Manufacturing Processes Lecture Notes

UNIT 1 – Casting Processes

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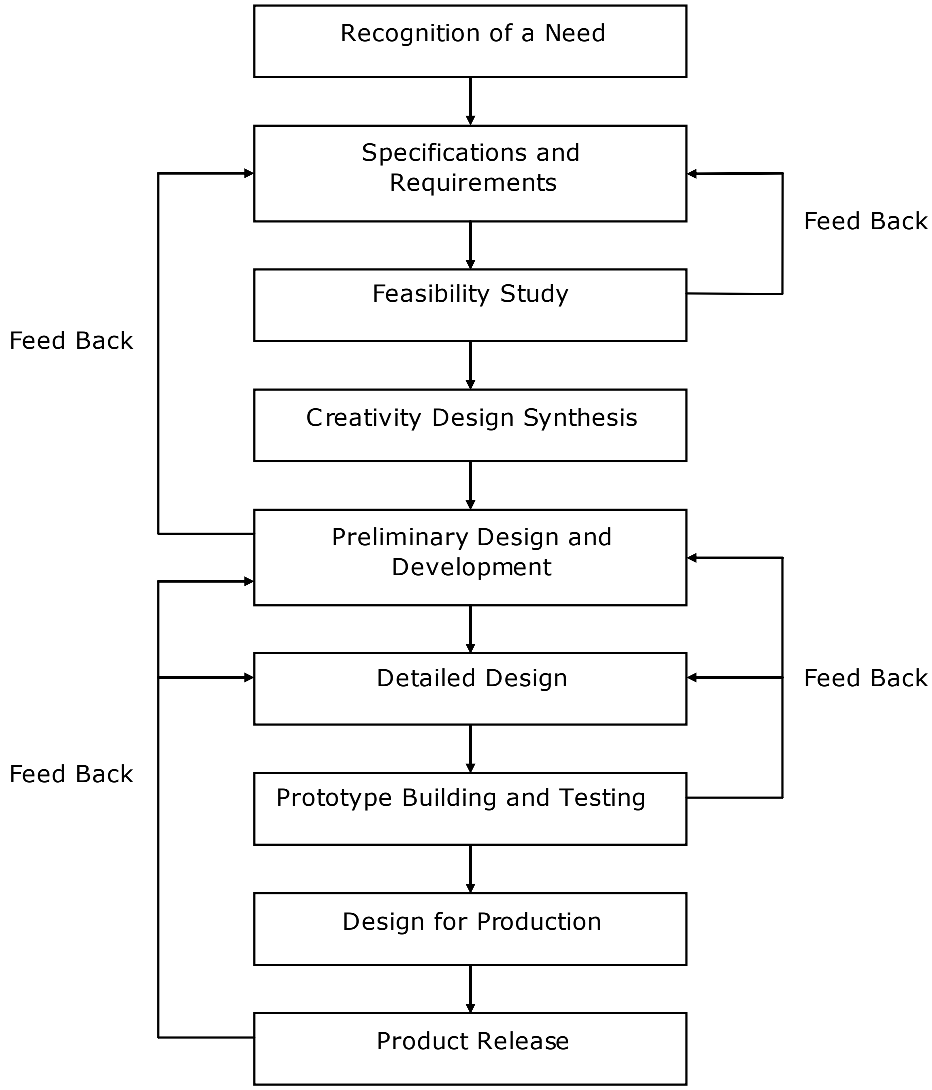
INTRODUCTION:

The main aim behind advances in engineering and technology has been to raise the standard of living of man and to make his life more comfortable. The major role in this direction has been played by manufacturing science. Manufacturing is an essential component of any industrialized economy. The word 'Manufacturing' means the making of goods and articles by hand or by machinery. Thus 'Manufacturing engineering' or "Production Engineering" can be defined as the study of the various processes required to produce parts and to assemble them in to machines and mechanisms. Production or Manufacturing is a critical; link in the design cycle, which starts with a creative idea and ends with a successful product, refer below figure.



Design Cycle

CLASSIFICATION OF MANUFACTURING PROCESSES:

When one thinks as to how the various components of machines are produced components of machines are produced, many techniques come to the mind, for example, casting, forging, rolling, machining, welding etc. The manufacturing processes are so varied that there is no simple and universally accepted criteria of classifying these. However, all the manufacturing processes may be grouped into the following main categories:

1. Casting Processes: Here, the metal in the state is poured into a mould and allowed state is poured into a mould and allowed to solidify into a shape. The mould may be expendable or permanent.

The examples are: Sand casting, Permanent mould casting, Die casting, Precision investment casting and centrifugal casting etc.

2. Deformation Processes: In these processes, the material is plastically deformed i.e., hot or cold under the action of an external force, to produce the required shape. No material is removed, but is only displaced and deformed to get the final shape. This category includes metal working/forming processes such as : forging, rolling, extrusion and drawing etc. and also sheet metal working processes such as deep drawing and bending etc. The unconventional forming processes such as High Energy Rate Forming (HERF) and High Velocity Forming (HVF) methods also fall under this category.

3. Machining Processes: In machining processes, also known as Metal cutting or chip forming processes, material is removed from a work piece to get the final shape of the product. The processes include: Turning, milling, drilling, broaching, shaving, grinding, polishing, lapping, honing, buffing and sawing etc. The modern unconventional machining processes such as ECM, EDM, USM, AJM and LBM etc. are included in this category.

4. Plastic materials/Polymers processing methods: Under this category are included the various methods for processing plastic materials/ polymers, for example, shape casting, the various moulding processes (compression moulding, injection moulding, transfer moulding etc.) and thermoforming etc.

5. Powder Metallurgy: The more appropriate name should be "Particulate Processing Methods". Here, the particles of various sizes of metals, ceramics, polymers, and glass etc. are pressed to shape and then sintered to get the final product.

6. Joining Processes: Here, two or more components are joined together to produce the required product. The category includes all the welding processes, brazing, soldering, diffusion bonding, riveting, bolting, adhesive bonding etc.

7. Heat treatment and surface treatment processes: Heat treatment processes are employed to improve the properties of a work peace. The category includes the processes like Annealing, normalizing, hardening and tempering methods. Surface treatment processes include electro-plating and painting etc.

8. Assembly processes: The assembly process for machines and the mechanisms is the part of the same manufacturing process concerned with the consecutive joining of the furnished parts into assembly units and complete machines, of a quality that means the manufacturing specifications.

It is evident from above that, in general, no component can be produced entirely by one single category of manufacturing processes. For example, the starting material for the forging process is in the form of bar, stock or billet, which are the end-products of rolling process. And, for the rolling process, the starting material id 'ingot', which is produced by casting process. Metal casting processes are normally used to give the final shape and size (surface finish, dimensional accuracy) to the components made by the other processes.

Accordingly, all the manufacturing processes can be grouped into two main categories:-

(i) Primary manufacturing Processes: These processes are involved in the initial breakdown of the original material to shapes that are then processed for the final product.

For example: casting, forging, rolling, extrusion, powder metallurgy and plastic technology.

However, in many cases, parts produced by these processes do not need other processes for producing the final shape and size.

For example: precision investment casting, die castings, precision forgings, powder metallurgy parts and parts produced by plastic processing methods.

(ii) Secondary Manufacturing Processes: These processes take the products of some primary process and change their geometry and properties to the semi finished or finished stage.

Example: all metal removal processes and the rest of the metal forming processes, that is, drawing, spinning, swaging, coining, stretching, bending, deep drawing, wire/rod/tube drawing, sheet metal forming and rubber forming etc.

FOUNDRY: The solidified piece of metal, which is taken out of the mould, is called casting. A plant where the castings are made is called a 'Foundry'. It is a collection of necessary materials, tools and equipment to produce a casting. The casting process is also called as "Founding". The word Foundry is derived from Latin word "fundere" meaning "melting and pouring".

TYPES OF FOUNDRIES; All the foundries are basically of two types:

(i) Jobbing Foundries: These foundries are mostly independently owned. They produce castings on contract, within their capacity.

(ii) Captive Foundries: Such foundries are usually a department of a big manufacturing company. They produce castings exclusively for the parent company. Some captive foundries which achieve high production, sell a part of their output.

CASTING:

Casting is probably one of the most ancient processes of manufacturing ma metallic components. Also, with few exceptions, it is the first step in the manufacture of metallic components.

These are the only processes where liquid metal is used. Casting is the one of the oldest known processes and also first step in manufacturing of most products.

The process involves the following basic steps;

1. A solid material usually a metal is first melted.
2. Pouring it into a previously made mould or cavity (made by pattern) which conforms to the shape of the desired component.
3. Allowing the molten metal to cool and solidify in the mould.
4. Removing the solidified component from the mould, cleaning it and subjecting further treatment, if necessary.

The solidified object or piece of metal, which is taken out of the mould, is called as "Casting".

Casting processes are universally used for manufacturing a wide variety of products. Extremely large, heavy metal objects can be made with casting process. Casting of even 200 ton can be made. Casting processes are best option when it is difficult to economically impossible to produce by any other process.

There are number of casting processes available which may be broadly classified as sand casting processes and contemporary or special casting process.

(i) Sand casting process: In sand casting process sand is used as primary material for making moulds. Sand casting process is used for most commercial metals. The process is equally suitable for production of very small batch as well as very large scale. These are used or producing large size objects.

(ii) Contemporary or special casting process: Whenever the size of casting is not large and production is on a large scale, specialized casting process offers cost saving. Some of the specialized casting process are:

1. Shell moulding casting
2. Precision investment casting
3. Permanent mould casting
4. Die casting
5. Centrifugal casting

SAND MOULD CASTING:

This process accounts for about 80% of the total output of cast products. This sand moulds are single casting moulds and are completely destroyed for taking out the casting, after the metal has solidified in the mould cavity. The moulding material is sand which is mixed with small amounts of other materials like binders and additives and water to improve the cohesive strength and moulding ability of sand. For making the mould, the moulding material will have to be consolidated and contained around the pattern. The metallic container is called as flask. There can be one flask or more than one flask. The most common design is two flask systems. In the assembled position the upper flask is called "Cope" (Cope Box or Cope Flask) and the bottom one is called "Drag" (Drag Box or Drag Flask). In three flask system, the central flask is called "Cheek". One flask design is used in 'Full Mould Process' or in 'Pit Moulding', where it is used as cope, the pit acting as the drag.

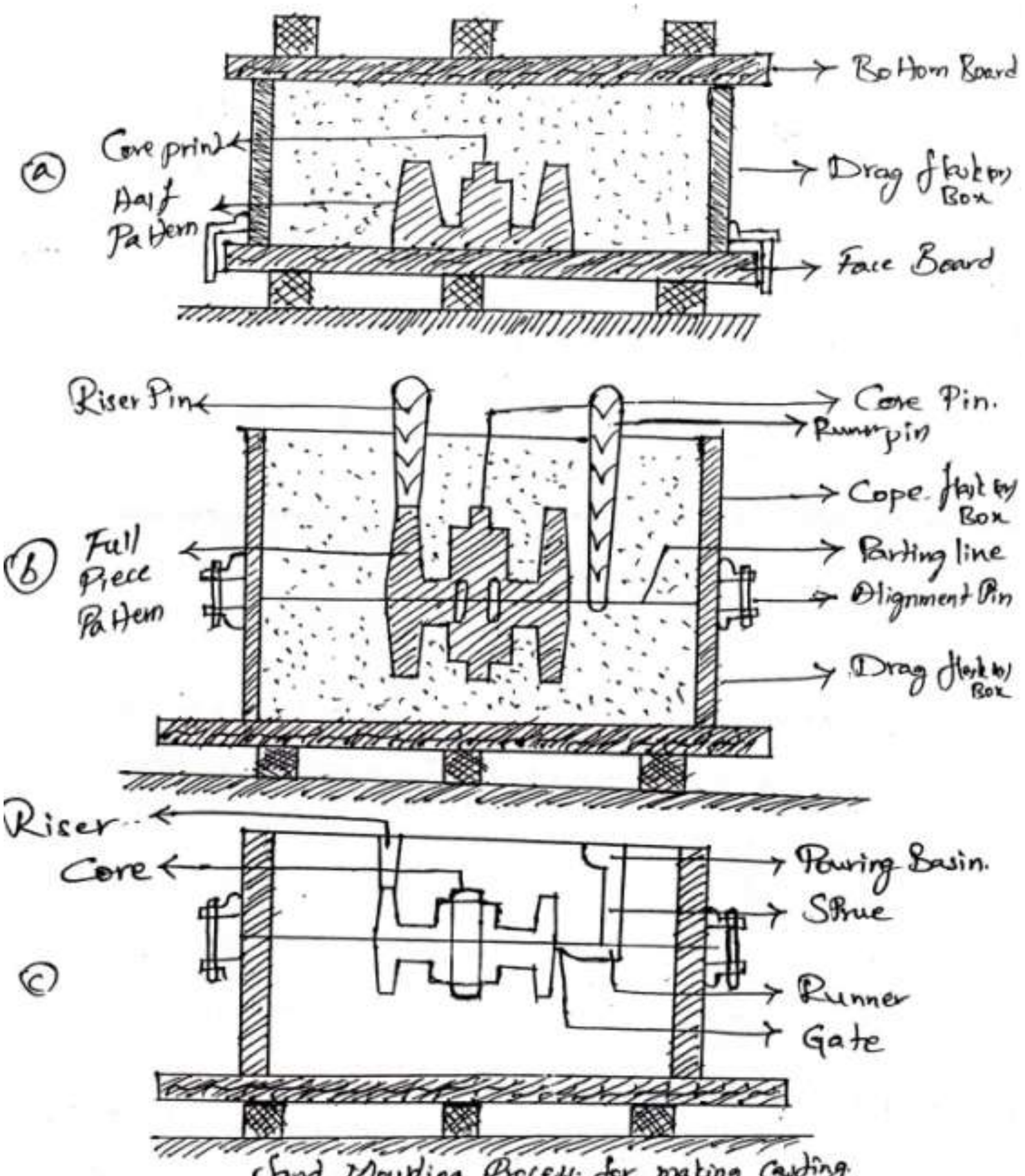
Depending upon the type of pattern used, the sand mould casting process is of two types:

1. Permanent or Removable Pattern Process: Here the pattern is removed from the mould cavity, before the molten metal is poured into the mould cavity. This is the most common sand mould casting process.

2. Expendable or Disposable Pattern Process: Here the pattern is not removed from the mould cavity, before the molten metal is poured into the mould cavity. It gets melted and forms a part of the final casting

PREPARING A SAND MOULD FOR CASTING:

The sequence of operations performed in the making of a sand mould is given below. For this, a green sand mould and a split pattern have been chosen. The appropriate split pattern is made which is split into two equal parts at the parting plane and joined together with dowel pins. We will use a two flask system.



Sand Moulding Process for making Casting

1. The drag half of the pattern, that is the half dowel holes rather than dowel pins, is placed with the flat parting plane on a flat board called "Moulding Board".
2. The drag is placed over the moulding board with the alignment or locating pins downwards.
3. A parting material is dusted over the pattern and the moulding board to facilitate both the removal of the pattern from the mould and the separation of the two mould halves.
4. The drag is filled with moulding sand and it is packed and rammed around the pattern. The ramming is done manually with hands and with hand rammers made wood or iron. The sand should be properly rammed, that is neither too hard nor too soft. If it is too soft, the mould will fall apart during handling or during pouring and if it is too hard, gases produced on pouring will not be able to leave it. Pneumatic ramming or mechanical ramming can be used for large moulds.

5. After the ramming, the excess sand is scrapped off with a straight bar called a "Strike Rod".
6. Vent holes are pierced with in 15 to 20 mm of the pattern surface with "Vent Wires", for the gases to escape through.
7. A second moulding board is placed on the moulded drag half and clamped if the mould is too heavy to be turned over conveniently by hand. The mould is then turned over 180° and the original moulding board is removed.
8. The cope is mounted onto the drag and the two halves are properly aligned with the help of dowel pins.
9. The cope half of the pattern is properly positioned over the drag half of the pattern with help of dowel pins and dowel holes.
10. For making the sprue and riser, the sprue pin and riser pin are placed approximately 25 mm on either side of the pattern usually along the parting line passing through the alignment pins.
11. Steps 3 to 6 are repeated.
12. A pouring basin is cut adjacent to the sprue and then the sprue and riser pins are with drawn.
13. The cope is carefully lifted off the temporarily separated from the drag and placed on one side.
14. To take out the split pattern from the drag, "draw Spikes" are drawn into the pattern and the pattern is loosened from the sand by rapping them slightly in all directions with a wooden hammer called a "mallet". Then the pattern is lifted off with the help of draw spike. Before with drawing the pattern, the sand around it is moistened with a "Swab" so that the edges of the mould remain firm when the pattern is withdrawn.
15. The gate and runner are cut in the drag or both cope and drag, connecting the mould cavity and the sprue opening. Sometimes, the gate and runner are automatically made with the help of extensions on the pattern. If needed, all the cavity edges are repaired. Dirt remaining in the mould cavity is blown off with a steam of air. If core are to be used, they are properly placed in position in the drag.
16. The mould is now assembled, the cope being carefully placed over the drag so that the locating pins into the holes.
17. If the lifting force on the cope due to the hydraulic pressure of the molten metal is grater than the weight of the cope, the cope must either be clamped to the drag or else weights must be placed on the top of the edge.
18. The mould is ready for pouring.
19. Melt the metal or alloy to be cast.
20. Pour the molten metal or alloy into the mould cavity.
21. Allow the molten metal to cool and solidify. Remove the casting from the mould. This operation is called shake out.
22. Clean and finish the casting. The operation is called as "fettling".
23. Test and inspect the casting.
24. Remove the defects if any and if possible salvaging the casting.
25. Again inspect the casting.
26. The casting is ready for use of shipping.

DIFFERENT MOULDING METHODS:

Moulding processes in conventional foundry are classified as follows:

1. Bench Moulding: Bench type moulding is used for small castings. In bench moulding process green sand, dry sand or skin dried moulds can be made. In this hand ramming with loose pattern is employed which is slow and laborious method. Various bench mould methods are:

(a) Two – box moulding in which moulding box or moulding flask is made in two parts core and drag.

(b) Three – box moulding: when the pattern shape is such that two box moulding becomes difficult then three box moulding is used. The middle moulding box or moulding flask is called cheek.
(c) Stack moulding: when large number of small size casting are required (each having one flat surface) then this method can be used. There will be common passage for the molten metal running through the stack of intermediate boxes. A number of parts can be cast in single pouring operation.

2. Floor Moulding: When casting size increases and is difficult to handle the moulding is done on the foundry floor. This type of casting is used for medium and large castings. It is a slow and laborious method as it requires ramming with loose patterns. Green sand, dry sand or skin dried moulds can be made by this method. The moulding is carried out usually using moulding flask having two parts – cope and drag.

3. Pit Moulding: This method is used for moulding extremely large casting. Here castings are moulded in a pit instead of a flask. The pit acts as drag part of the flask and a separate cope is used above it. This pit has sides and bottoms constructed of reinforced concrete. At the bottom of the pit, a bed of charcoal may be placed to aid the escape of gases. After pouring, these large castings should be allowed to cool slowly in the mould to prevent the formation of excessive residual internal stresses.

4. Machine Moulding: Machine moulding is usually when small castings are produced in large numbers. In some cases they may also be used for production of small numbers of casting. Here machines perform a number of operations that are ordinarily dome by hands. Operations like ramming the sand, rolling the mould over, forming the gate and withdrawing the pattern are performed much better and more efficiently by machined than by hand. Thus mould and cores made are better faster and less skill is required of the workman.

AIMS or ADVANTAGES IN MAKING A CASTING:

There are basically two reasons for making a casting.

1) Liquid metal must be solidified before further processing is possible.

2) To produce finished or semi-finished articles. The various reasons under this second category, which are of more importance, can be

(a) Casting is often the cheapest and most direct way of producing a shape with certain desired mechanical properties. Desired mechanical properties can be attained by operations like suitable control of alloy composition, grain structure and heat treatment.
(b) Casting is best suited where components are desired in low quantities as high cost of mechanical working processes like tolling, forging, extrusion etc… requiring heavy equipment can be justified only when components in large quantities are required.
(c) Certain metals and alloys such as highly creep resistant metal based alloys for gas turbines can't be worked mechanically and can be cast only.
(d) Intricate shapes having internal openings and complex sectional variations can be produced quickly and economically by casting since liquid metals can flow into any form, whereas tooling and machine costs in mechanical working would be too high to produce them.
(e) Heavy equipment like machine beds, ships propellers, etc… can be cast easily in the required size rather than fabricating them by joining several smaller pieces.
(f) Casting is best suited for composite components requiring different properties in different sections. These are made by incorporating prefabricated inserts in a casting, some examples are: steel screw threads in zinc die castings,

aluminium conductors into slots in iron armatures for electric motors, wear resistant skins onto shock resistant components etc…

ELEMENTS OF CASTING PROCESSES:

The metals most frequently cast are iron, steel, aluminium, brass, bronze, magnesium, certain zinc alloys, and nickel based super alloys. Of this cast iron is the dominant casting material, primarily because of its low cost, good fluidity, low shrinkage, ease of control and wide range of properties including useful strength and rigidity.

The important terms which are using in making moulding and casting process are given below in brief:

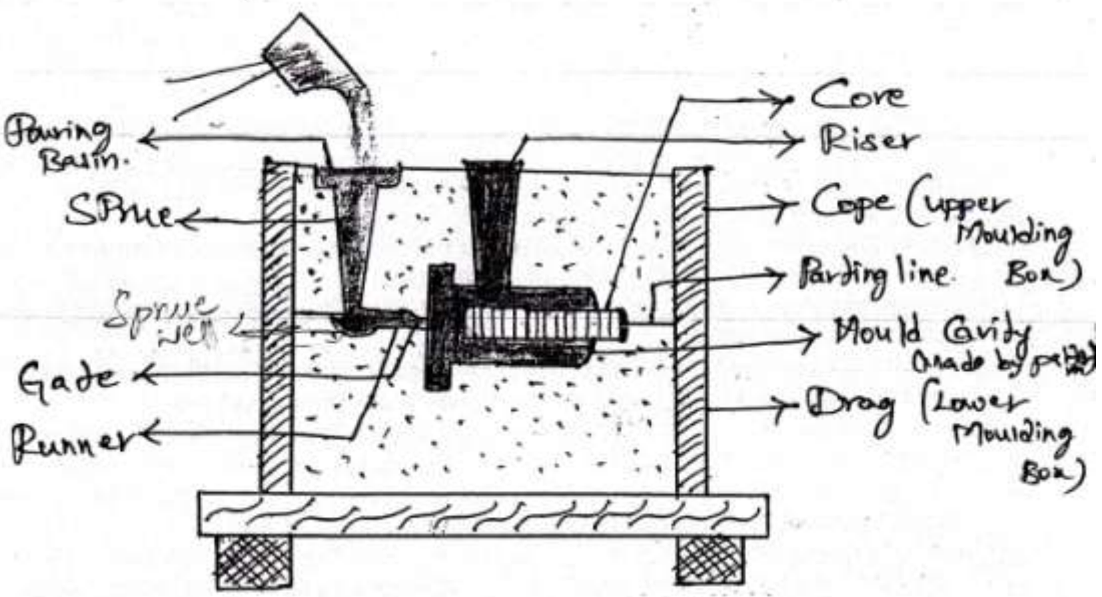
(a)Moulding Flask: The box like frame without top and bottom base into which sand is rammed is called "flask". It holds the sand mould intact. It is made up of wood for temporary applications and more generally of metal for long term use. It is generally made of two or more parts.

Drag: Lower or bottom moulding flask is known as drag.
Cope: Upper moulding flask is termed as cope.
Cheek: It is an intermediate moulding flask in three piece moulding.

Drag is provided with the pins and cope is provided with lugs with hole which fit together and ensures proper alignment during the placement of cope upon drag.

(b)Parting Line or Parting Surface: It is the surface or line that separates the cope and drags halves of the mould. In split piece pattern it is also the dividing line between two half's of the pattern.

(c)Bottom Board: This is the board normally made of wood which is used at starting of mould making. The pattern and drag is first kept on the bottom board, sand is sprinkled and ramming is done in the drag.



Two Part Moulding & Components of Casting Process.

(d)Pattern: Pattern is the duplicate of final casting to be made with some modifications. It is used for making the mould cavity.

(e)Core: Core is placed in moulding cavity to make hole or hollow cavities through the castings. Core is made up of core sand.

Basic difference between core and pattern: Although both core and pattern are used to give desired shape to the castings. The removable pattern never comes in contact molten metal because its purpose is to form mould cavity and it is always removed before pouring the molten metal. Whereas core is present in the mould while pouring the molten metal and is always subjected to severe thermal stresses as core is present in the mould while pouring the molten metal. The materials used for pattern are wood, plastic and may be metal when large numbers of casting are required. The material used for making core is core sand.

(f)Core Box: Core boxes are used for imparting the desired shape to the core sand. Core boxes can also be defined as mould or die used to produce cores. Core boxes are made up of wood, or metal.

(g)Core Prints: Core prints are provided to locate and support the core within the moulds and hold them in proper position while filling the mould. Core print is a region added to the pattern, core or mould.

(h)Chaplets: Chaplets are the metallic support kept inside the mould cavity to support the core. These should be of same composition as that of pouring metal. They melt and fuse with molten metal during solidification and become the integral part of finished casting. The use of chaplets should be minimized because they usually cause casting defects.

(i)Chills: Chills are metallic objects of high heat capacity and are placed in mould to provide the uniform rate of cooling or to achieve desired rate of cooling. Chills may be external or internal chills.

Internal chills melt during the operation and ultimately become part of the casting so internal chills must be made from the same alloy as that being cast. Thin portion of casting would normally cool before section and set up internal stress due to uneven contraction. If a chill is placed as shown the rate of cooling is equalized and risk of distortion of casting of minimized.

(J)Gating System: All those elements which are related to flow of molten metal from ladle to the mould cavity are referred as elements of gating system.

The elements of gating system are pouring basin, sprue, runner, gates and riser. We will discuss this gating system in brief after casting process.

STEPS IN CASTING MAKING PROCESS:

Following are the basic steps in the making of sand castings. Any detailed operation may be categorized as belonging to one of these fundamental steps;

1. Pattern making
2. Core making
3. Mould making (Moulding)
4. Melting and pouring
5. Solidification and mould breaking
6. Cleaning and finishing

1. **Pattern Making:** The casting process starts with construction of a pattern. Pattern is the duplicate of the final casting with some modifications; these modifications are discussed in pattern allowances. Patterns are required to make moulds. The mould is made by packing the moulding sand around it.

When the pattern is withdrawn its impression provides the mould cavity which is ultimately filled with molten metal to make casting.

2. **Core Making:** Cores are made of core sand. Basically core is a sand shape that is kept inside the mould cavity to produce holes or hollow cavities in the castings. With the core any complicated shape can be easily obtained which can not be normally produced by pattern alone.

3. **Mould Making:** Mould making consists of all operation necessary to prepare mould for receiving molten metal. Mould making for two piece mould involves following operations.

   (i) Placing drag half of pattern and lower moulding flash drag in position.
   (ii) Pouring of sand and ramming up the drag.
   (iii) Rolling over the drag and placing the cope half of pattern on drag half of pattern with help of dowel pins. Also cope upper moulding flask is placed over the drag.
   (iv) Locating sprue pin, riser pin and ramming up the core.
   (v) Removing sprue pin, riser pin and pattern.
   (vi) Making of runner and gate.
   (vii) Setting the core in mould.
   (viii) Closing the mould.

4. **Melting and Pouring:** After the moulding, melting is the major factor which controls the quality of casting. Melting simply means preparation of molten metal. There are number of methods available for melting such as pit furnace, open hearth furnace, cupola furnace etc.

   Pouring means transferring the molten metal from furnace to the mould. Some type of pouring device or ladle is required for pouring. Proper pouring technique must be used so that adequate amount of molten metal at desired temperature with minimum contamination should be supplied to mould. Thus producing a high quality casting which is free from defects.

5. **Solidification and Mould Breaking:** After pouring the metal into the mould, the casting is allowed to solidify and cooled in the mould itself. The sand mould is to be broken to extract the casting. The breaking of sand mould is to be done only when the casting is sufficiently cooled since the metal at high temperature has very little strength. Removing the casting from mould is not very difficult in sand casting as the mould is destroyed after each casting but with multiple use mould, however, removal of complex shaped casting may present a major design problem.

6. **Cleaning and Finishing:** After the castings are removed from the moulds various cleaning and finishing operations are required to remove of sand, scale and excess metal from the casting surface. Excess metal is cut off. For removing the sand particles sticking to metal surface sand blasting is normally used. Tumbling is also used for cleaning the casting surface.

ADVANTAGES, LIMITATIONS & APPLICATIONS OF CASTING PROCESS:

Advantages;

1. Parts like both small and large of intricate shapes can be produced.
2. Almost all the metals and alloys and some plastics can be cast.
3. A part can be made almost to the finished shape before any machining is done.
4. Good mechanical and service properties.

5. Mechanical and automated casting processes help decrease the cost of castings.
6. The number of castings can vary from very few to several thousands.
7. Necessary tools required for casting moulds are very simple and inexpensive.
8. Casting process is highly suitable for small lot as well as mass production.
9. Castings are generally cooled uniformly from all sides and therefore, they are expected to have no directional properties.
10. It is possible to cast practically any material be it ferrous or non ferrous.

Limitations;

1. Casting imposes severe problems from the point of view of material properties and accuracy.
2. A complicated sequence of operations is required for metal casting.
3. The dimensional accuracy and surface finish achieved by normal sand casting processes is not adequate for final applications in many cases.
4. With some materials it is often difficult to remove defects arising out of moisture present in sand castings.

Applications;

There is hardly any machine or equipment which does not have one or more cast components.

The list is very long, for example,

- automobile engine blocks,
- cylinder blocks of automobile and airplane engines,
- pistons and piston rings,
- machine tool beds,
- machine frames,
- mill rolls,
- wheel and housings of steam and hydraulic turbines,
- turbine vanes,
- aircraft jet engine blades,
- water supply and sewer pipes,
- sanitary fittings,
- Agricultural parts etc…

PATTERNS:

A pattern is an element used for making cavities in the mould, into which molten is poured to produce a casting. It is not an exact replica of the casting desired. There are certain essential differences. It is slightly larger than the desired casting, due to the various allowances like shrinkage allowance, machining allowance etc. and it may have several projections or bosses called core prints. It may also have extensions to produce runners and gates during the moulding process.

The requirements of a good pattern are:

1. Secure the desired shape and size of the casting.
2. Cheap and readily repairable.
3. Simple in design for case of manufacture.
4. Light in mass and convenient to handle.
5. Have high strength and long life in order to make as many moulds as required
6. Retain its dimension and rigidity during the definite service life.
7. Its surface should be smooth and wear resistant.
8. Able to withstand rough handling.

MATERIALS USED FOR PATTERNS:

The common materials used in pattern making include "wood, metal, plastic and quick setting compounds. Each material has its own advantages, limitations and field of application. Also, the required accuracy, strength and life of a pattern depend on the quantity of castings to be produced. Based on the above factors, we can choose the pattern material as follows:

(i) Piece and short run production – wood
(ii) Large scale and mass production – Metal, being more durable than wood, though costlier.
(iii) Batch Production – Plastics for example, epoxy resins and also from gypsum and cement.

(a)Wood: The wood used for pattern making should be properly dried and seasoned. It should not contain more than 10% moisture to avoid warping and distortion during subsequent drying. It should be straight grained and free from knots.

Advantages:

1. Light in weight.
2. Comparatively inexpensive.
3. Good workability.
4. Lends itself to gluing and joining.
5. Holds well varnishes and paints.
6. Can be repaired easily.

Limitations:

1. Inherently non uniform in structure.
2. Posses' poor wear and abrasion resistance.
3. Can not with stand rough handling.
4. Absorbs and gives off moisture, so that it varies in volume, warps and thus changes its mechanical properties.

These drawbacks, however, can be remedied by drying and seasoning it and then giving coats of water proof varnishes and paints.

The following types of wood are commonly used for pattern making;

(i) White Pine: It is the most widely used wood, because of its straight grain and light weight and because it is soft, easy to work and unlikely to warp.
(ii)Mahogany: It is harder and more durable than white pine. Can be worked easily if straight grained. It is less likely to wrap than some of other woods.
(iii) Maple, Birch and Cherry: These woods are harder and heavier than white pine. They tend to warp in large sections, so should be used for small patterns only. They should be carefully treated, because they pick up moisture readily.

The other common wood materials are Teak, Shisham, Kail and Deodar.

(b) Metal: A metal pattern can be either cast from a master wooden pattern or may be machined by the usual methods of machining. Metal patterns are usually used in machining. Metal patterns are usually used in machine moulding.

Advantages:

1. More durable and accurate in size than wooed pattern.
2. Have a smooth surface.
3. Do not deform in storage.
4. Are resistant to wear, abrasion, corrosion and swelling.
5. Can with stand rough handling.

Limitations:

1. Expensive as compared to wood.
2. Not easily repaired.
3. Heavier than wooden patterns.
4. Ferrous patterns can get rusted.

The common metals used for pattern making are:

(i) Cast Iron: With this fine grain can be used as a pattern material. It has low corrosion resistance unless protected. Heavier and difficult to work. However it is cheaper and more durable than other metals.

(ii) Brass: May be easily worked and built up by soldering or brazing. It has a smooth, closed pore structure. It is expensive therefore generally used foe small cast parts.

(iii) Aluminum: It is the best pattern material, because it is easily worked, light in weight and is corrosion resistant. It is however subject to shrinkage and wear by abrasive action.

(iv) White Metal: It has low shrinkage, can be cast easily, has low melting point, is light in weight and may be built up by soldering. However, it is subject to wear by abrasive action of sand.

(c)Plastics: The use of plastics for pattern material results in following advantages;

1. Facilitates the production process.
2. Makes it more economical in cost and labour.
3. Plastic patterns are highly resistant to corrosion, lighter and stronger than wood patterns.
4. Moulding sand sticks less to plastics than to wood.
5. No moisture absorption.
6. Smooth surface of patterns.
7. Strong and dimensionally stable.

Various plastic patterns make good materials for the production of patterns. These are the compositions based on epoxy, phenol formaldehyde and polyester resins; polyacrylaes, polyethylene, polyvinylchloride and others. In most wide use are cold curing plastics based on epoxy resins and acrylates.

Plastic patterns are made by one of the following methods:

(i) By injecting a plastic material into a die.
(ii) Utilizing laminated construction by building up successive layers of resin and glass fibre.
(iii) By pouring a plastic material into a plaster mould.

Gypsum patterns are capable of producing castings with intricate details and to very close tolerances. The two main types of gypsum are soft "Plaster of Paris" and hard metal casting plaster. However soft plasters do not have the strength of hard plaster. Gypsum can be easily formed, has plasticity and can be easily repaired.

After the patterns are made, they should be finished by sanding so that tool marks and other irregularities are erased. Then they should be applied with 2 to 3 coats of shellac. Shellac fills up the pores and imparts a smooth finish.

The finish of the casting depends on the finish of the pattern. If the pattern is to be preserved for a long period and if a color scheme is to be used good quality enamel paint should be selected to spray or brush paint it.

PATTERN ALLOWACES:

Pattern allowances means the dimensions of the pattern are slightly different from the final dimensions of the casting. This difference is required because of various reasons which are as follows:

(a) Shrinkage Allowance: All metals shrink while cooling except bismuth. To compensate for shrinkage the pattern is slightly larger in every dimension.

The rate of shrinkage or contraction with temperature is different for different materials. For example steel contracts to a higher degree as compared to aluminium.

Shrinkage allowances for various metals

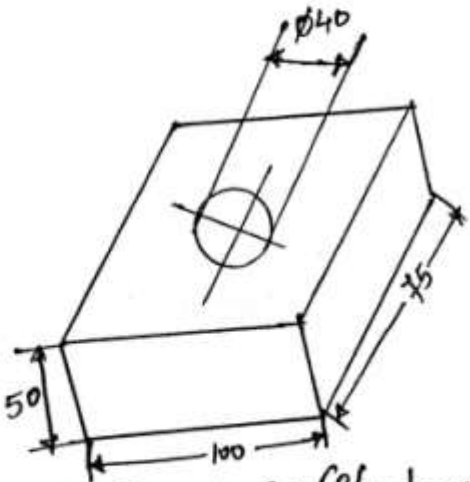
Material (Non Ferrous)	Shrinkage allowance (mm/mm)
Aluminium	0.0130
Aluminium Bronze	0.0200 to 0.0230
Brass	0.0155
Copper	0.0100 to 0.0160
Lead	0.0260
Magnesium	0.0130
Magnesium alloys	0.0160
White metal	0.0060
Zinc	0.0100 to 0.0150

Material (Ferrous)	Shrinkage allowance (mm/mm)
Grey cast iron	0.0105
White cast iron	0.0160 to 0.0230
Plain carbon steel	0.0210
Chromium steel	0.0200
Manganese steel	0.0250 to 0.0380

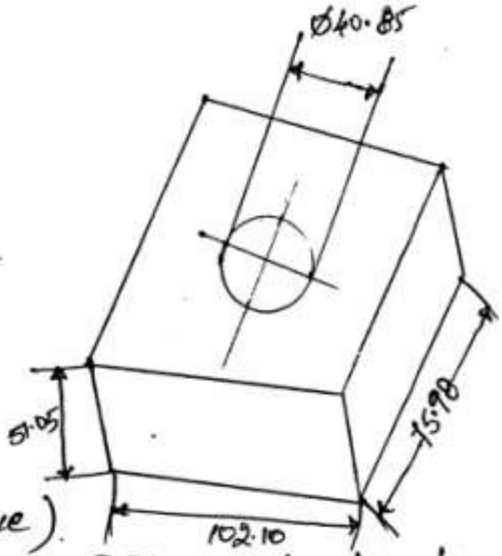
It may be noted that there are two types of shrinkages in casting:

1. **Liquid Shrinkage:** Liquid shrinkage means reduction in volume when the metal changes from liquid to solid state. To account for this shrinkage risers are provided.
2. **Solid Shrinkage:** Solid shrinkage is the reduction of volume caused when solid metal loses its temperature i.e., from high temperature to room temperature. In solid state the shrinkage allowance are provided take care of this reduction.

To compensate shrinkage allowance all the dimensions of casting are altered uniformly unless they are constrained in some way. For example, dry sand core at the centre of casting may constrain the casting fro, contraction but edges are not constrained so it may be desirable to provide a higher shrinkage allowance for outer dimensions as compared to those which are constrained.



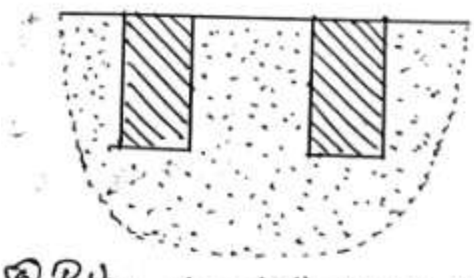
(a) Part tobe Cast (Shrinkage Allowance)



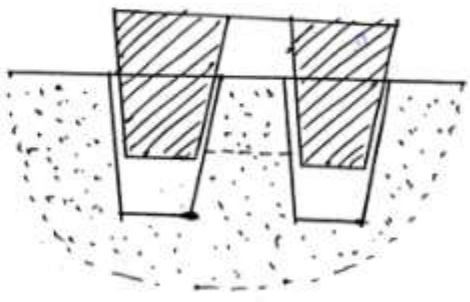
(b) Dimensions of pattern when steel parts is cast.

(b) Draft Allowance: While withdrawing the pattern from sand mould the vertical faces of the pattern may damage with mould cavity. To reduce the chances of this happening vertical faces of pattern are always tapered from parting line. Thus the pattern horizontal section is largest at the parting and becomes smaller the deeper it goes into sand. This is called draft.

a. Draft allowance varies with the complexity of the job. For external surfaces it is normally 1° and for inner surfaces, holes and pocket up to 3° may be provided.
b. One thing is to be noted that draft is added to the original dimension of casting thus making pattern slightly larger.



(a) Pattern where draft allowance is not provided, it may damage mould Cavity while removing the pattern.



(b) Pattern with draft allowance, reduces the chance of damage of mould Cavity.

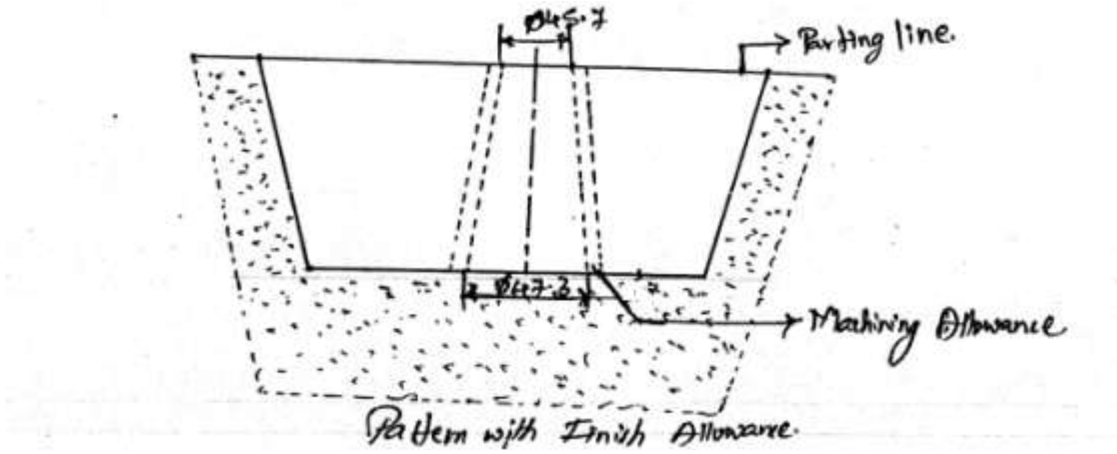
Draft value for patterns

Pattern	Outer Draft Angle (in degrees)	Inner Draft Angle
Plastic	0.25 to 1.00	0.35 to 2.25
Wood	0.25 to 3.00	0.50 to 3.00
Metal	0.35 to 1.50	0.50 to 3.00

(c) Finish or Machining Allowance: The finish and dimensional accuracy obtained in sand casting are generally poor, and when dimensional accurate part is to be produced, it is achieved by subsequent machining operation.

(i) Also ferrous material would have scale on surface which is to be removed. Hence extra metal is provided which is removed by machining or cleaning process. The amount of extra metal depends on the dimensions, casting material and surface finish required.

(ii) Machining allowance of some materials are shown in table.

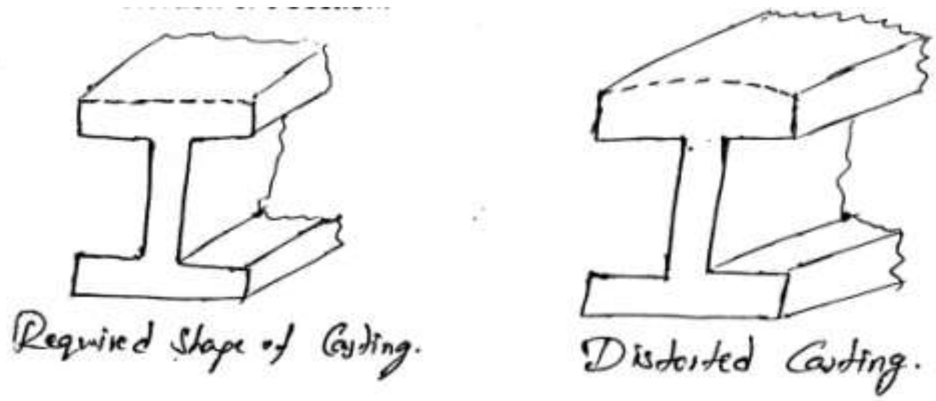


Machining allowances on patterns

Dimensions (mm)	Bore allowance	Surface allowance (mm)	Cope side Allowance
Non – ferrous metals			
Less than 200	2.0	1.5	2.0
200 to 300	2.5	1.5	3.0
300 to 900	3.0	2.5	3.0
Cast Iron			
Less than 300	3.0	3.0	5.5
300 to 500	5.0	4.0	6.0
500 to 900	6.0	5.0	6.0
Cast steel			
Less than 150	3.0	3.0	6.0
150 to 500	6.0	5.5	7.0
500 to 900	7.0	6.0	9.0

(d) Distortion Allowance: Certain objects such as long flat plate, U – shaped casting, V – section or complicated casting which have thin and long section are distorted in the process of cooling because of metal shrinkage. So extra metal is provided to reduce the distortion of such object.

Figure shows the distortion of I section.



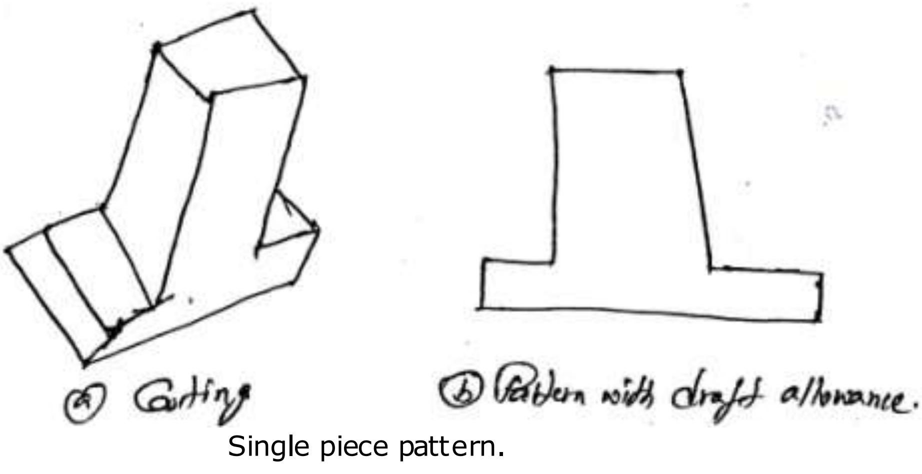
(e) Shake Allowance: In all the allowances mentioned above the dimensions of pattern are larger than the cast component. But shake allowance is negative allowance. Before the pattern is withdrawn from sand mould, it is rapped to enlarge mould cavity slightly which make the removal of pattern easy. In average size casting this increase in size can be ignored but in large size casting shake allowance is considered by making the pattern slightly smaller. One way of reducing this allowance is to increase the draft which can be removed during subsequent machining.

PATTERN TYPES:

There are many type of patterns used in foundry industry. Selection of pattern is usually based on complexity of the part, number of castings required and moulding procedure adopted.

Following are the pattern types used in foundry shop.

(a) Single Piece Pattern: As the name suggest single piece pattern are the simplest and often least expensive type to make.



Single piece pattern.

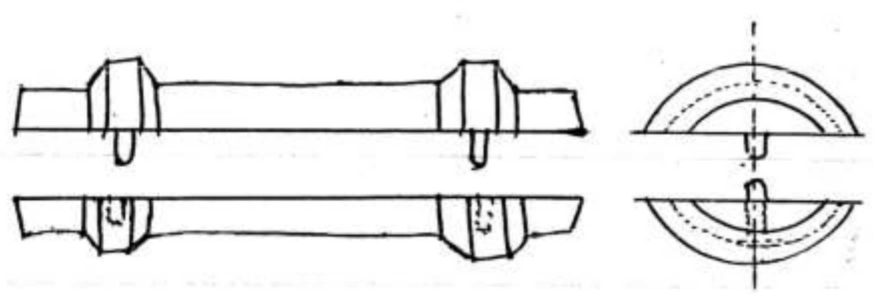
(i)These are used when the shape of casting is simple and does not create problems while with drawing the pattern from the mould. The above figure represent casting and single piece pattern corresponding to the casting. As discussed earlier various allowances are provided while manufacturing the pattern. Draft allowance is shown in pattern.
(ii)These are generally used when number of casting required is rather small.
(iii)The pattern is expected to be entirely in drag box. If the shape of pattern is complex and contains no flat surface then moulding may become complicated with

the necessity of follow board. This is a time consuming process and requires a skilled worker.

(b) Split Piece Pattern: Many patterns can not be made in single piece because they cannot be removed from mould. To eliminate this problem some pattern are made in two parts. Lower half of pattern rests in drag box while upper half of pattern is in cope box i.e., upper box.

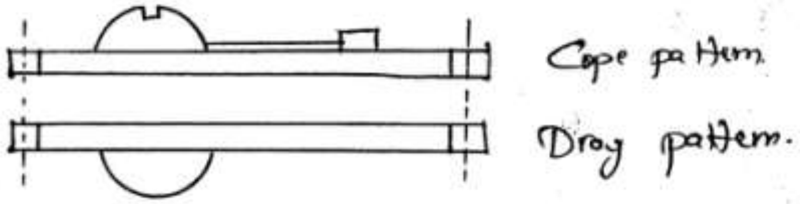
The split surface of pattern is same as the parting plane of the mould. The two halves of pattern should be aligned properly by making use of dowel pins which are fitted to the upper cope half pattern. These dowel pin match the precisely made hole in the lower half drag box of the pattern.

These patterns are also used when the depth of casting is too high or when moderate quantities are to be made.



Split piece Pattern.

(c) Cope and Drag Pattern: These type of patterns are generally used for moulding medium and large castings. However, they can also be used for producing small castings. These are similar to split pattern. Cope and drag half of the pattern along with gating and rising system are attached separately to metal or wooden plates along with alignment pins. Thus cope and drag mould can be produced independently on moulding machine using these plates. Then they are assembled to from complete mould. In this way large mould can be handled more easily in separate mould and small moulds can be made at faster rate.

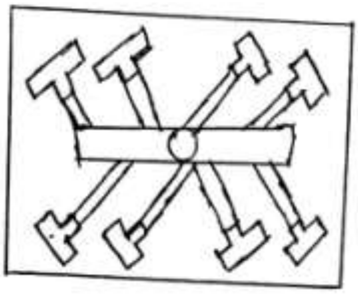


Cope and Drag Pattern

(d) Match plate patterns: When large quantity of small casting is to be produced with higher dimensional accuracy then match plate patterns are used. It is the extension of cope and drag patterns.

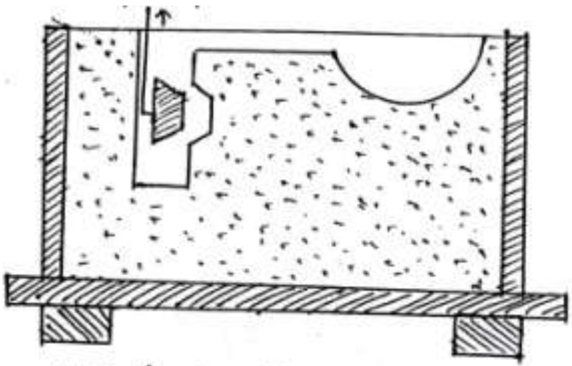
In this cope and drag halves of the split match plate along with gates and raisers are permanently attached t the opposite sides of single match plate which is made up of wood or metal. One side is moulded in the drag and after turning over, the cope side is moulded. The upper and lower moulding boxes are now separated and match plate pattern is removed. Using lugs with hole and alignment pin, cope and drag are reassembled in proper alignment.

The below figure shows the casting of 8 components at once in the match place with pattern as shown.



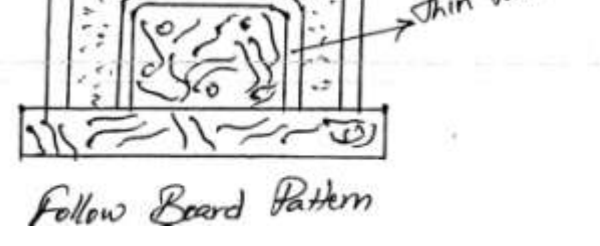
→ Plate with 8 Patterns.

(e) Loose Piece Pattern: When the shape of part is such that one piece or split pattern could not be removed from moulding sand, loose piece pattern may be used. During the moulding obstructing part of the pattern is held as loose piece by a wire. After the moulding is over first the main pattern is removed then the loose pieces are removed through the cavity generated by removal of main pattern. One advantage of loose pattern is that some shifting is possible during mould making. Loose piece pattern are expensive and moulding with loose piece is a highly skilled job. However they enable the sand casting of complex shape which would other wise require other processes. Whenever, possible design changes should be considered that would eliminate the need for loose piece pattern.



Withdrawl of loose piece after removing the pattern from mould.

(f) Follow Board Pattern: These types of patterns are used where some portions of pattern are structurally weak and if not supported properly are likely to break under the force of ramming. Hence the bottom board is modified as follow board. Fellow board is provided with projection or cavity corresponding to the shape of pattern. Actually fellow board acts as a seat for the patterns. During the preparation of core no fellow board is necessary because the sand which is rammed in drag will support the weak portion of pattern.



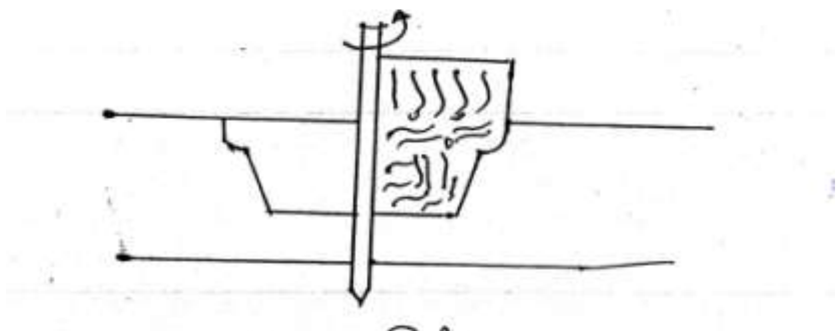
Follow Board Pattern

(g) Master Pattern: A master pattern, usually made of wood, is used as an original for casting metal patterns. Several patterns may be cast from the master patterns and mounted on the pattern plate after they have been finished to the proper dimensions. Master pattern may be the first step to obtain match plates. Most metal pattern are cast in sand mould from a wooden master pattern provided with double shrinkage allowance.

(h) Sweep Patterns: It is the one of the type of special pattern. These type of patterns are used for producing large casting, particularly which are circular in cross section and are axis symmetrical like bell shape castings or large kettles of cast iron. The main advantage of this pattern is that it eliminates the cost of manufacturing in a three dimensional pattern.

The equipment consists of a base suitable placed in sand, a vertical spindle and a wooden template called sweep. The sweep consists of flat board and on the one end has the shape corresponding to the shape of desired casting. The sweep is rotated about the spindle to form the mould cavity like if conical cavity is desired the shape of sweep will be fight angle triangular plane. When this plane will rotate about the edge the conical cavity will be formed.

Sweep and spindle are then removed leaving the base in sand. The hole made by removal of spindle is filled up by sand. Hence cavity is prepared. If shape desires then we may place core and chaplets in the cavity.



Sweep Pattern.

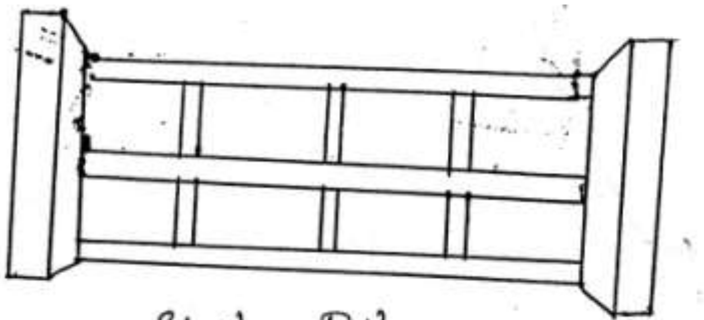
(i) Segmental Pattern: These patterns are used for producing large circular castings avoiding the use of solid pattern of exact size. Segmental pattern differs from sweep pattern in the sense that sweep is given a continuous revolving motion to generate desired shape, whereas a segmental pattern is a portion of solid pattern itself and mould is prepared in parts by it. In the use of this pattern a vertical central spindle is first firmly fixed near the center of drag and after preparing the part mould in one position the segment is moved to the next position. The process is continued until a complete circular mould cavity has been made. A large cast gear can be moulded with a segmental pattern with only three to four teeth.

Segmental Pattern.

(j) Skeleton Pattern: These patterns are ideal when preparation of a regular solid pattern would be too expensive and the shapes to be cast permit their use. A skeleton pattern is merely a wooden frame. The space between wooden frames is filled with moulding sand. The exact over all shape is obtained by firmly pressing the sand and strickling it. Skeleton pattern for round shape such as pipes and cylinders are prepared in cope and drag halves.

In some instances cope drag and interior core may all be formed from same skeleton pattern, there by saving the expense of large core box.

The below figure shows the skeleton pattern for casting a large diameter flanged pipe.



Stelton Pattern

GATING SYSTEM:

The molten metal from ladle is not introduced directly into the mould cavity, because it will strike the bottom of the mould cavity with a great velocity and can cause considerable erosion of the bottom of the mould cavity. Due to this, the molten metal is introduced into the mould cavity from the ladle, through a gating system. The gating system for a casting is a series of channels which lead molten metal from the ladle into the mould cavity. It may include any or all of the following,

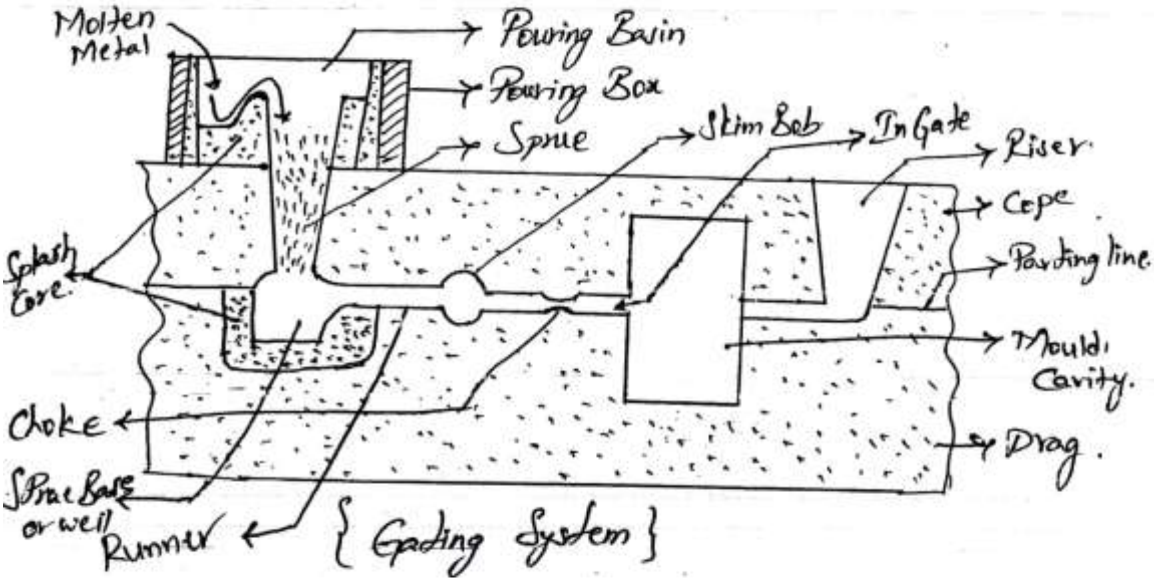
1. Pouring Bain
2. Sprue
3. Sprue Base or well
4. Runner
5. Choke
6. Skim Bob
7. Gates or ingates
8. Riser

Elements of gating system have a great impact on the quality of casting produced. The gating system should be designed in such a manner that defect free casting is produced.

The following points should be considered while designing the gating system:

1. The metal should enter the mould cavity with as little turbulence as possible.
2. The metal should enter the mould cavity at minimum optimum flow rate. High flow rate causes erosion of gating system and mould cavity where as low flow rate can result in casting defects like misrun and coldshut.
3. Proper thermal gradient should be maintained so that cooling takes place without shrinkage, cavities and distortion.
4. Molten metal flow through gating system should be properly controlled in such a manner that absorption of gases and atmospheric air is prevented.
5. Unwanted materials like sand particles, slag and dross should not be allowed to enter the mould cavity.

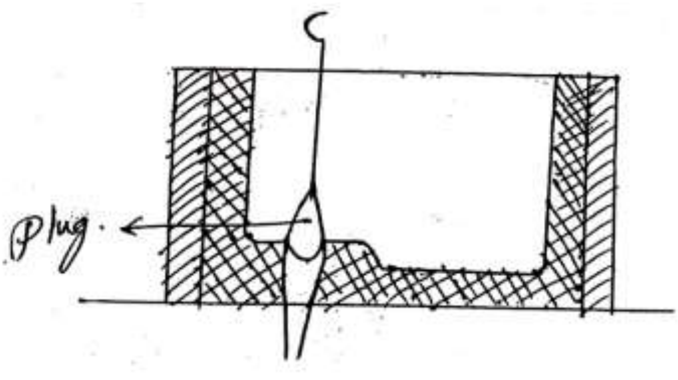
6. The gating system chosen should be economical, easy to operate and removable after solidification.



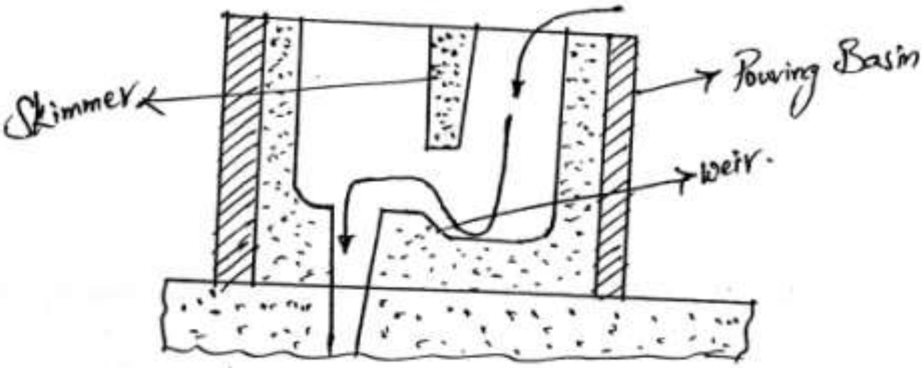
1. Pouring Basin: A pouring basin or cup is a reservoir at the top of the sprue that receives the stream of molten metal poured from the ladle. Some times the metal is directly poured into the top of the sprue, which is made with a funnel shaped opening.

The pouring basin may be moulded into the cope at the top of the sprue, or it may be made of core sand and placed on the cope above the sprue. The pouring basin is filled quickly at the start of the pour and it should remain full of molten metal during pouring. Thus dross consisting of oxides and slags which float may be kept from entering the sprue.

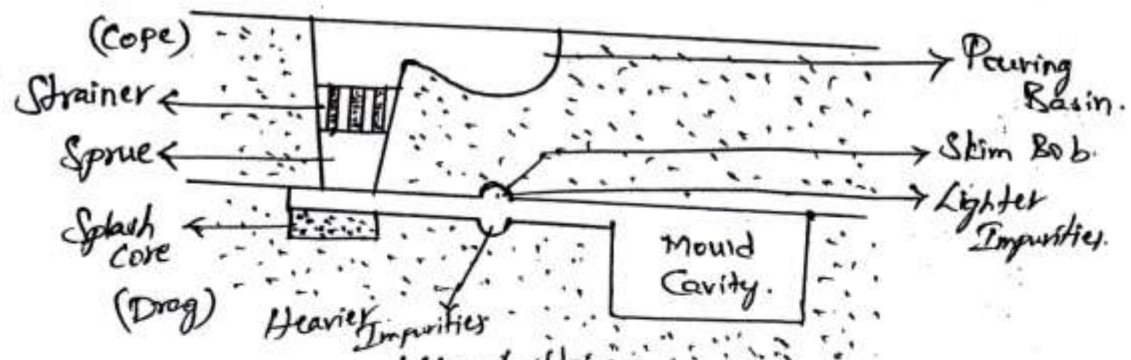
To prevent the slag from flowing down the sprue, it is sometimes useful to close the sprue entrance with a plug or tin plates and allow the molten metal to fill the basin. The plug is then lifted off.



There can be many designs of pouring basins, but the most commonly used one is shown in below figures. The metal must be poured into the pouring basin that is remote from the sprue entrance. If the metals poured directly down the sprue entrance, lot of vortexing and turbulence take place, resulting in unsound and defective casting. However when the metal is poured into the far low side of the pouring basin, a dam effect enables the operator to reach and optimum pouring speed before any metal enters the sprue. The weir will hold back the heavier inclusions and the skimmer or dam will bold back the dross.

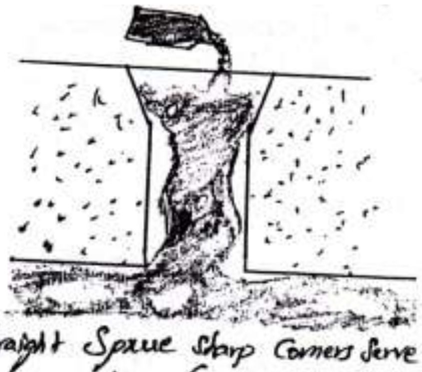


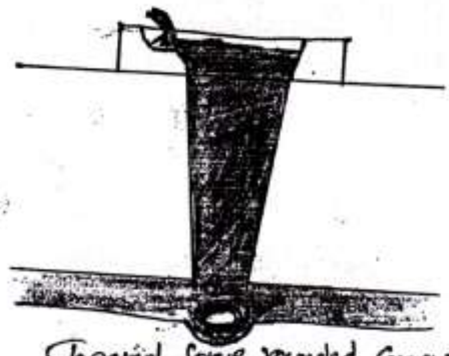
Another means of preventing slags from entering the sprue and hence the mould cavity is to use a ceramic strainer at the top of the sprue. The strainer is made from core sand, chamotte and refractory fibre materials. The strainer is maintained in the pouring basin for constant flow of molten liquid and also controls the slag.



Use of Strainer.

2. Sprue: Sprue is the vertical portion of gating system through which molten metal is brought into the parting plane from where it enters the runners. Sprue is gradually tapered and having reduced cross sectional area as it moves down from top of cope as shown in figure. This is because molten metal moving from top gains velocity downwards and as result requires smaller cross sectional area for same volume flow rate. If the sprue has straight cylindrical shape low pressure region will be created and atmospheric air may be sucked into this low resume region and may cause casting defects like air inclusions and blow holes.


Straight Sprue Sharp Corners Serve aspirations (air entrapment)


Tapered Sprue rounded Corners negligible aspirations.

When runner is partially full, slag is not effectively trapped and may enter mould cavity along metal.

3. Sprue Well or base: Where a sprue joins a runner, usually an enlargement in the runner is made. This enlargement which is called as "Sprue Base" or "Sprue Well" serves a dual function. A molten metal pool is an excellent device for preventing excessive sand erosion where the molten metal impinges on the runner at the sprue base. Also, there is sudden slowing of flow which dissipates kinetic energy and helps to drop out inclusions, scum and various other refractory materials that may have been washed in with the molten metal.

4. Runner: Runner is a horizontal channel located in parting plane which connects the sprue to gates and allowing the molten metal to enter mould cavity. Runners are normally made trapezoidal in cross section. It is a normal practice to cut runners in the cope and gates in the drag. The main reason behind this is to trap the slag and dross which are lighter and thus trapped in the upper portion of runners. When the amount of molten metal flowing from sprue is more than amount flowing through gates, runner would be always full and thus slag would be trapped effectively. On the other hand when the metal coming through gates is more than that flowing through the runners then runner would be partially filled and slag would enter the mould cavity as shown in fig. Formed runner and gates resist the erosion better than those are cut in mould.

5. Choke: The choke is that part of the gating system which has the smallest cross sectional area. Its function is to control the rate of metal flow to help lower the flow velocity in the runner, to hold back slag and foreign material and float these in the cope side of the runner and to minimize sand erosion in the runner.

Gate Ratio: It is defined as the ratio of sprue base area, followed by the total runner area and the total ingate area. The sprue base area is taken as unity.

Depending upon its location, the gating system may be classified as;

(i) Pressurised or choked system.
(ii) Unpressurised or free system

Pressurised gating system: In this system, the ingates serve as the choke. This system maintains a back pressure and causes the entire gating system to become pressurized. It is usual to cut runners in the cope and gates in the cope and gates in the drag. And since in the pressurized system the runner flows full, the slag will remain in the runner while floating up to its upper section. The system will flow full even if a straight sprue is used once the flow has been established. The full flow system will minimize aspiration and oxidation in the gating system. However the molten metal will enter the mould cavity with relatively high velocity, causing turbulence. This will cause erosion and oxidation in the mould cavity. But in this system the molten metal will enter the mould cavity uniformly through all the gates. A typical gating ratio in this system can be 1: 0.75: 0.50

The gating ratio is defined as the ration between Sprue area, Runner area, and Ingate area.

→ Gating Ratio = Sprue area: Runner area: Ingate area = 1: 0.75: 0.50

Unpessurised gating system: In this system, the sprue base serves as the choke. Typical gating ratios in this system can be, 1 : 2 : 4 or 1 : 4 : 4.

This system reduces velocity and turbulence and hence minimizes erosion and oxidation in the mould cavity. But, since the system will not flow full, it may favour absorption of gases and oxidation of metal in the gating system. Also, the slag will not float up and will get access to the mould cavity. This system must have tapered sprues, sprue base wells and pouring basins. This system can deliver metal uniformly to multiple gates only if the runner is reduced after each gate.

For casting alloys such as light metals and manganese bronze, usually the unpressurised system is used in contrast, for casting heavy and ferrous metals, pressurized system has been used. However, according to Briggs, for high quality steel castings, a gating ratio of 1 : 2 : 2 or 1 : 2: 1.5 will produce castings nearly free from erosion and will minimize oxidation which in turn gives uniform flow.

6. Skim Bob: A skim bob is an enlargement along the runner, whose function is to trap heavier and lighter impurities such as dross or eroded sand. It thus prevents these impurities from going into the mould cavity.

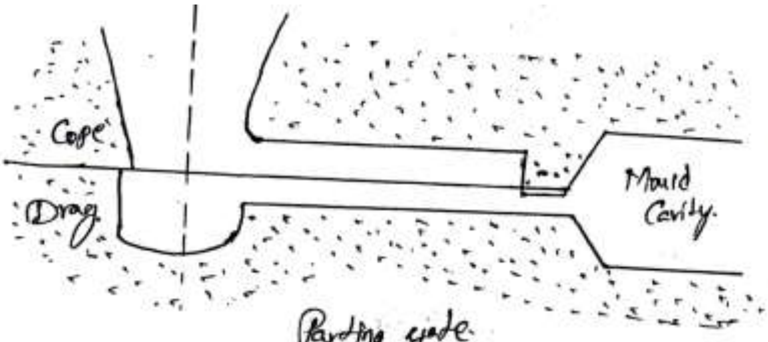
7. Gates / Ingates: Gates are channels which connect the runners to the mould cavity and through which the incoming metal directly enters into the mould cavity. The gates should break off easily from the casting after solidification. For this at the junction to the cavity, the gates are much reduced in thickness. This will also choke the flow of metal and ensure its quiet entrance into the mould cavity. From experience, the best cross section for gates is a trapezoidal one that smoothly passes into a rectangular section at the junction of the cavity.

Ingate: This is the end of the gate where it joins the mould cavity and through which the molten metal will be introduced into the mould cavity.

Depending upon the applications and specific requirements there are various types of gates. They are:

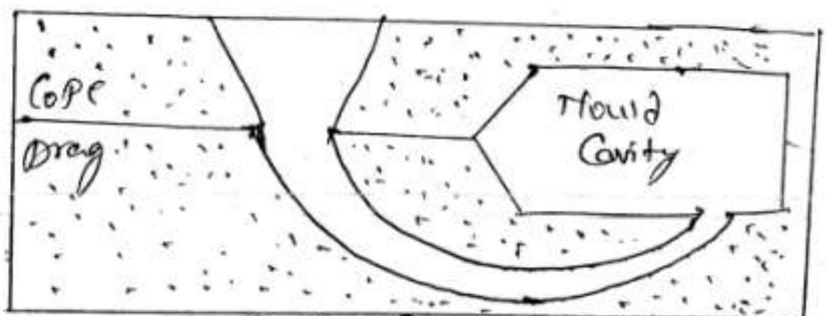
1. Parting gate
2. Bottom gate
3. Top gate
4. Step gate.

Parting Gate: Parting gate is most common gate used in sand castings. As name suggests metal enters the mould cavity at the parting plane separating cope and drag as shown in fig. this parting gates are very easy to make as they forms in the parting surface.



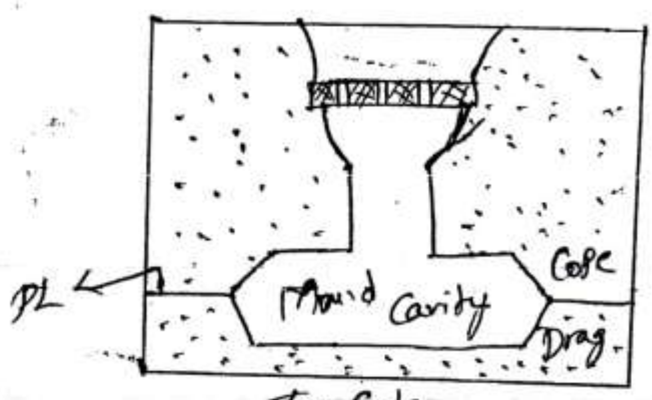
Parting gate

Bottom Gate: Bottom gates are used to overcome the difficulty of mould erosion of deep moulds. Here the metal enters of the mould cavity at the bottom of the mould. The molten metal slowly rises in the mould cavity and it takes somewhat higher time for filling the mould. The preparation of bottom gate requires special sprue or special cores.



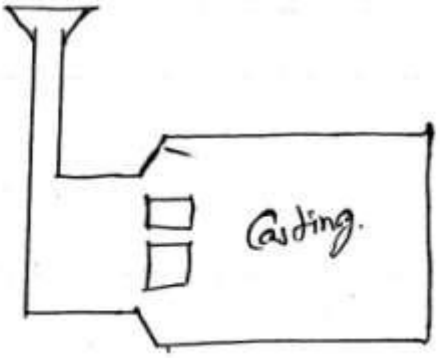
Bottom Gate.

Top Gate: As the name suggests, in this case all metal enters the mould cavity from top as shown in fig. Since the metal which enters first reaches at the bottom and hotter metal is at the top and a favourable temperature gradient is created. Also the mould fills quickly in this gate. Top gating is suggested only for ferrous metal castings which are of simple shape and having a little depth. To reduce the mould erosion pencil gates are provided in pouring cups.



Top Gate

Step Gate: The step gate ensures gradual filling of mould without mould erosion and produces good quality castings. Step gates are used for deep, heavy and large castings. The molten metal enters the mould cavity through a number of side gates as shown in fig. It ensures the gradual filling of mould without any mould erosion and produces a good quality casting.



Step Gate

8. Risers: Risers are the added reservoirs provided in mould to feed molten metal into mould cavity to compensate for the shrinkage. In order to make the risers effective, following points should be kept in mind while designing them:

- The metal in risers should remain molten as long as possible and should solidify after the casting.
- The riser should be located near heavy sections subjected to large shrinkage.
- The volume of riser should be sufficient for compensating the shrinkage in castings.

The risers are of various types:

1. Top risers: Top risers are located on top of castings. They are convenient to make and occupy less space with in the mould. A top riser of open type is shown in above fig.
2. Side risers: Side risers are located adjacent to the mould cavity. They are placed on parting line. Side riser of blind type is shown in above fig.
3. Blind risers: Blind risers are in the cope half of the mould and are not open to the atmosphere. It is surrounded by moulding sand and losses heat slowly, so they are more effective.
4. Open riser: If the risers are open to atmosphere they are known as open risers.

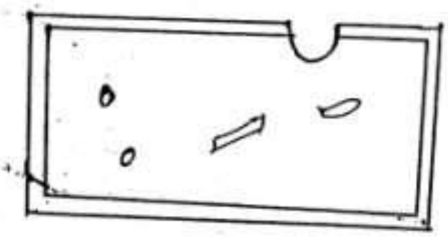
Defects in Casting:

Casting defects are usually not accidental but due to improper control of manufacturing. The major defects generally found in the sand castings are as follows:

1. Gas defects
2. Shrinkage Cavities
3. Moulding material defects
4. Pouring metal defects
5. Metallurgical defects
6. Moulding and core box defects

1. Gas Defects: These are blow holes and open blows, air inclusions and pin hole porosity. These are due to lower permeability of the mould.

(a) Blow holes and open blows: These are in the form of spherical, flattened or elongated cavities present inside the cavity or on the surface as shown in fig. On the surface, they are called open blow holes. These are due to the moisture left in the mould and the core. Due to heat of the molten metal, the moisture is converted into steam, a part of which may entrap in the casting. Apart from the moisture, they occur due to the lower venting and lower permeability of the mould.



Blow Holes.

(b) Air Inclusions: The atmospheric and other gases absorbed by the molten metal in the furnace, in the laddle and during the flow in the mould when not allowed to escape, would be trapped inside the casting. The main reason for this defect is the higher pouring temperatures which increase the amount of gas absorption.

(c) Pinhole Porosity: This is due to the hydrogen in the molten metal. The hydrogen while leaving the solidifying metal would cause very small diameter and long pinholes.

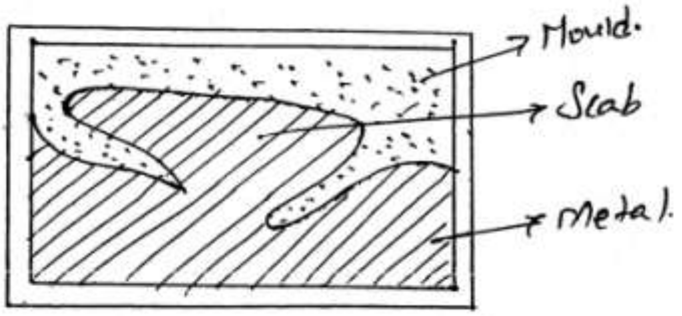
2. Shrinkage Cavities: These are caused by the liquid shrinkage occurring during the solidification. To compensate this, proper feeding of the liquid metal is required. Also proper casting design.

3. Moulding Material Defects: Scabs, swell, run out and drop. These defects occur because of the moulding materials are not having required properties or due to ramming.

(a) Scabs: These are projections on the casting which occur when a portion of the mould face lifts and metal flows underneath in a thin layer. In other words, liquid metal penetrates behind the surface layer of sand. (see below fig.)

These scabs are of two types: 1. Expansion scabs, 2. Erosion scabs.

Expansion scab is caused by the expansion of the surface layers of the sand. It may occur where metal has been agitated or has partly eroded the sand.



Scabs occur due to uneven ramming, excess moisture in the sand.

(b) Swell: Under the influence of the metallostatic forces, the mould wall may move back causing a swell in the casting.

It may occur due to insufficient ramming of the sand, pouring the molten metal too rapidly.

(c) Run out: This occurs when the molten metal leaks out the mould cavity. This may be caused either due to faulty mould making or because of the faulty moulding flask.

(d) Drop: A drop occurs when cope surface cracks and breaks, thus the pieces of sand fall into the molten metal. This is due to either low green strength or improper ramming of the cope flask.

4. Pouring Metal Defects: The defects in this category are misrun, cold shut, poured short.

(a) Misrun: When the mould is not completely filled with molten metal due to some obstruction in the form of metal, the defect is called misrun.

(b) Cold shut: Sometimes metal is poured from opposite directions in the mould. If the two streams of metal approach each other, make physical contact, but do not fuse together thus leaving a gap, the resulting defect is called 'cold shut'. The reasons for cold shut or misrun may be too thin sections, improper gating system, slow and intermittent pouring and poor fluidity of metal.

(c) Poured Short: When the mould cavity is not completely filled because of insufficient metal, the defect is called 'poured short'.

5. Metallurgical Defects: Hot tears and Hot spots.

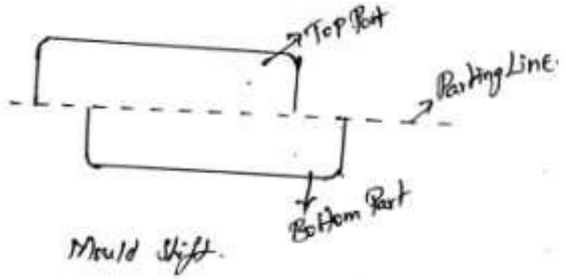
a) Hot Tears or Hot Cracks: These are internal or external ragged discontinuous or cracks on the casting surface, due to hindered contraction occurring immediately after the metal had solidified. These will occur when the casting is poorly designed.

(b) Hot spots: These are caused by the chilling of the casting. For example, with gray cast iron having small amounts of silicon, very hard white cast iron may result at the chilled surface. This hot spot will interface with the subsequent machining of this region. Proper metallurgical control is essential for eliminations of the hot spots.

6. Moulding and core Box Defects:

(a) Mould Shift (Mismatch): Shifts in a mismatch of cope and drag flasks at the parting line. The below figure shows the mismatch of the sections of a casting at the parting line. This is due to worn or loose dowels in the pattern made in halves. This defect can be prevented by ensuring proper alignment of the patterns or die parts.

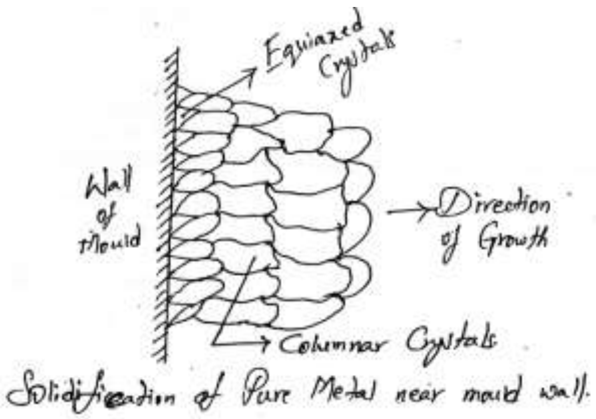
Core shift may also occur due to misalignment of cores or core halves during assembly.



(b) Fins: Thin projections of metal on the surface of the casting usually at the parting of mould or core sections. Moulds and cores incorrectly assembled will cause fins. Insufficient weight on the mould or improper clamping of the flasks may produce fin defect.

Solidification:

A thorough understanding of the mechanism of solidification, the rate of heat loss from the material to the mould etc… is essential to predict how the casting will solidify and thus avoid casting defects like seams, gas porosity, hot tears etc… Since solidification requires energy to produce a crystalline structure, some super cooling (cooling below the freezing point) is required before the liquid starts to solidify. It is provided by the walls of the mould which provide sites around which crystals can grow initially and subsequently by the solidified particles and the metal itself. So the crystals growing inwards until the whole of the metal has solidified. The crystals near the mould walls are small and equated i.e., their axes randomly oriented. On further solidification, crystals grow with their axes perpendicular to the mould and these are columnar in shape.



Concept of solidification:

To understand the good mechanism of solidification we have to know the basic concept that when the casting solidifies it shrinks or contracts in size. This shrinkage occurs in three stages:

- **(i) Liquid Contraction or Shrinkage:** This shrinkage occurs when the metal is liquid. It occurs when the molten metal cools from the temperature at which it is poured to the temperature at which solidification occurs.
- **(ii) Solidification Shrinkage:** This occurs when the metal looses its latent heat that is during the metal changes from the liquid state to the solid state.
- **(iii) Solid Shrinkage:** This occurs when the metal cools from freezing temperature to the room temperature.

Only the first two shrinkages are considered for risering purposes, since the third is accounted for by the pattern makers contraction allowance. Liquid shrinkage is generally negligible, but solidification shrinkage can be substantial.

As already discussed, when the mould cavity is filled with molten metal, the metal adjacent to the walls of the mould cools and solidifies first. This result in the shell of solid metal, with the centre of the section remaining liquid, while there is a zone between the liquid interior and solid exterior where in the metal is in a semi solid or mushy state. The solidification then proceeds inwards towards the same centre of the section. This solidification is called as "Lateral or Progressive Solidification". Longitudinal solidification occurs at right angles to the lateral solidification at the center line (as shown in fig.). The gating should be designed in such a manner that it permits solidification and cooling to progress in such a way that the accompanying shrinkage may take place without resulting in voids, cracks, or porosity with in the casting, so as to obtain a sound casting. This type of solidification is called "Directional Solidification". For this to occur, the following two conditions should be satisfied:

(a) The longitudinal solidification must progress from the thinnest faster cooling sections to the heavier hotter sections.
(b) The temperature gradient, in addition to being properly directed, must be sufficiently steep so that the liquid metal can pass through the wedge shaped channel to compensate for shrinkage as it occurs at the centre line. It implies that the progressive solidification is controlled in such a way that no portion of the casting is isolated from liquid metal feeding channels, during the complete solidification cycle.

If the depth of a section is quite large as compared to its cross section, then the progressive solidification rate will exceed the longitudinal solidification and result in fine center line porosity or even a larger or series of large cavities. To prevent such defects, the cross section of the casting should increase towards the hotter sections.

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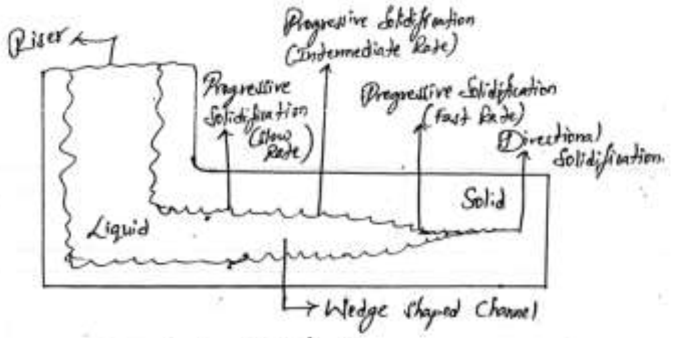


Directional Solidification.

Solidification of Casting:

Sound casting is one which is free from defects like porosity, shrinkage and cracks etc. In order to produce a casting free from such defects, it is essential to know cast structure developed during solidification of metals and alloys.

Recrystallization:

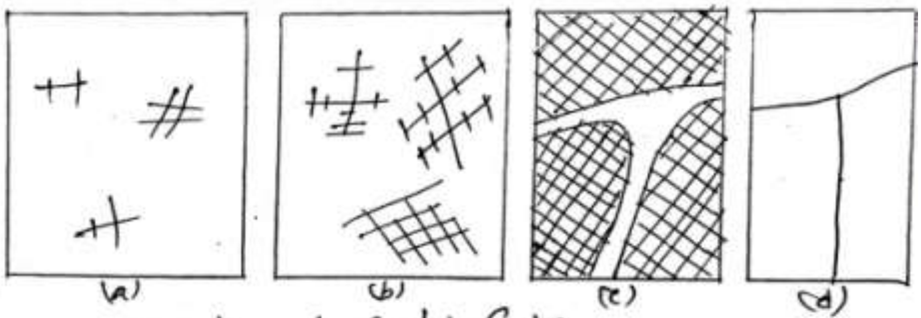
(a) In this process, old distorted grains are replaced by new equaixed stress free, strain free grains by a process a nucleation and growth. This is called Recrystallization.
(b) Nucleation occurs at the points of high energy and subsequently these nuclei grow at the expense of old grains. The probability of forming a nucleus is the same at every place a state suitable for homogeneous is said to be in the system.

(c) Nucleation occurs at the surface near the mould wall contains equidistanced grains and the nucleation is based on the volume of the particles formed i.e., free energy and the energy need to join the surface layer of the particle. The microstructure at the end of recrytallization process is similar to the original structure. The grains become equaixed and the dislocation density gets reduced to a value of strain free metal.
(d) Due to change in the microstructure of the casting metal, mechanical properties increases, internal stresses are reduced almost to the original level with increase in corrosion resistance.
(e) The grain size of the material obtained at the end of recrystallization depends on the temperature of heating, time of heating, heating rate and type end level of impurities.
(f) Insoluble particles lock the grain boundaries and prevent their migration. They also reduce the energy of grain boundaries. Due to this, a fine grain size rate sharply decreases.

Formation of Grains:

All the metals are crystalline and crystals are made up of several atoms. The individual crystals or grains together form the visible mass of a solid metal.

A grain is a crystal with almost external shape, but with an internal atomic structure based on the space lattice with which it was formed. The mechanical property of the metal varies with the arrangement of grains. The solidification process is shown in below fig.



Formation of Crystal Grains.

The metal begins to solidify when the temperature of the liquid metal drops below the critical temperature. When two or more atoms associated to form a small crystal called "Nucleus'. It happens in number of locations through out liquid metal. They are simultaneously cooled. Slow cooling favours growth of crystals uniformly in all directions of growth and give equaixed crystals i.e., the crystals with equal dimensions in all the direction. Rapid cooling always favours tree like crystals called "dendrites" which consisting of unit cells, with straight line branches.

Crystal grows until it come in contact with the adjacent crystal of proper geometrical form and having different orientations. They can be distorted by interface of each crystal with its neighbours.

The boundary formed between two adjacent crystalline growths because of different orientations of the grain is known as boundary.

- As shown in above figure the formation of nucleus in straight line branches is shown in (a).
- Crystals having the same geometrical from but different in orientations can be seen in (b) & (c).
- Grain boundaries formed between adjacent crystals can be seen in (d).

Grain Size:

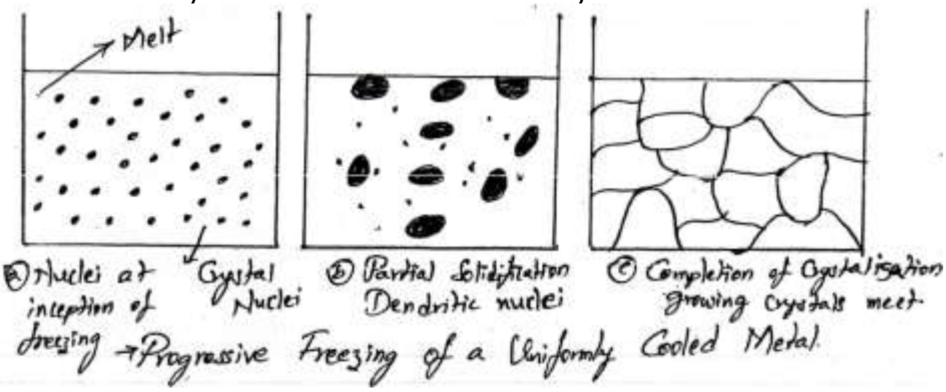
The rate of whole crystallization process is determined by the rate of nucleation (N) and rate of crystal growth (G). The size of the grain is determined by the rate of crystal growth (G) and rate of nucleation (N). At high value of G and low value of N, coarse grains are formed. Besides rate of cooling, the grain size also depends on factors.

- Temperature of liquid metal
- Impurities in metal
- Chemical composition

Solidification of Pure Metals:

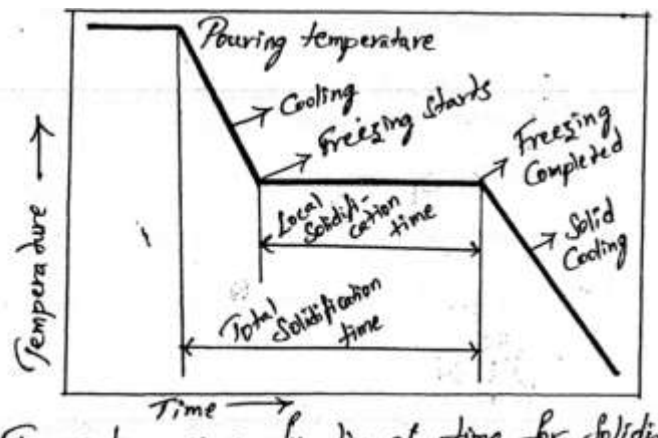
Solidification process differs from pure metal to the alloys as it is the transformation of the molten metal back to the solid state.

As the pure metal have sharply defined freezing temperature which is the same melting point composed of the small group of atoms oriented into common crystal pattern (See below figure). The process occurs in the overtime called a cooling curve. During the process of solidification nuclei spring up, each nucleus grow and able to form the crystal which is visible to the eye.



As each nucleus grows, the atoms within it are having the same orientation. When the nucleus has grown to the point, they absorb all the liquid atoms and come in contact with each other along their boundaries. The boundaries do not line up the plan of atoms, change direction from one crystal to other so solid state composed of a number of crystals of different orientation i.e., mixed crystals.

The actual freezing takes time called "Local Solidification Time" in casting during which the metals latent heat of fusion is released into the surrounding mould. The total solidification time is the time taken between pouring and complete solidification. After the casting is completely solidified, cooling gradually increases by decreasing the slope of the cooling curve as shown in below figure.

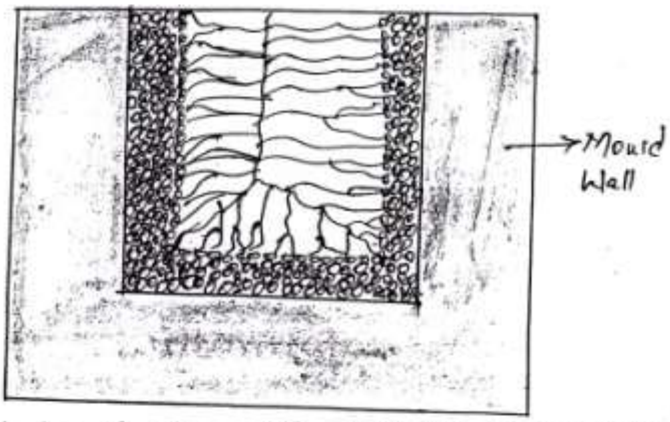


→ Temperature as a function of time for Solidification of pure metal

Because of the chilling action of the mould wall, a thin skin (a thin layer) is formed at the interface immediately after pouring. Thickness of the skin increases to form a shell around molten metal as solidification progress inward toward the centre of the cavity. The rate of freezing depends on the heat transfer in the mould.

As the conductivity of the mould is high, fine, equiaxed, random orientation atoms of small crystal grows neat the mould face. As the cooling progress, the grain formation in the direction away from the heat transfer gradually long columnar crystals, with the axis perpendicular to the mould face are formed.

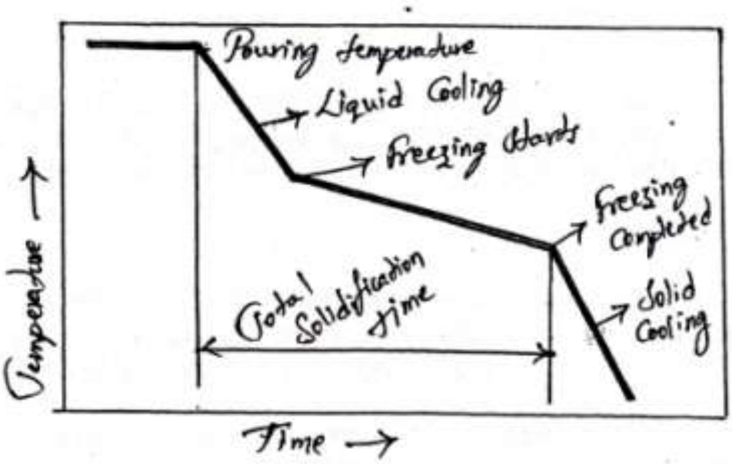
The beginning of solidification and end of solidification takes place at constant temperature in pure metals. These two points are called congruent melting points. Perfect crystals of proper external shape can be obtained only if crystallization develops under the degree of super cooling is very low and the metal is having high purity. In most of the cases it leads to the formation of branches form at right angles to the first branch (Tree like crystals) called dendrites as shown in below figure.



→ Grain Structure of Casting of Pure Metal Showing Randomly Oriented Fine, Equiaxed Grains near the Mould wall and Large Columnar Grains Oriented towards Centre of Casting.

Solidification in Alloys:

Most alloys freeze over a temperature range rather than at a single temperature. The exact range depends on the alloy stem and the particular composition. This can be explained with reference to the phase diagram as shown in below figure.

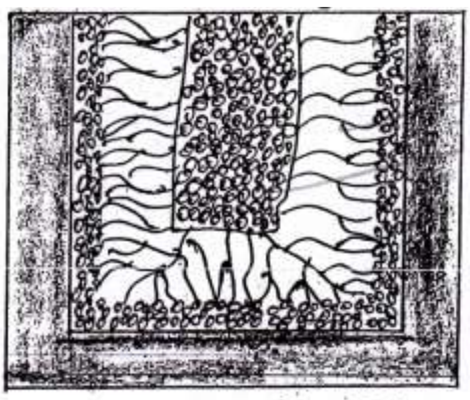


→ Temperature as a function of Time for Solidification of an Alloy.

Just below the solidification starts the solid phase start separating out from the liquid. As the temperature decreases, the freezing begins from the liquids line and is completed when the solidus is reached. As similar to the pure metal the freezing starts by forming a thin skin at the mould wall due to large temperature gradient at the surfaces and dendrites grow away from the surface of the mould wall where both liquid and solid metal together. This solid region has a sort of consistency leading to its name as "Mushy Zone". As the freezing progress the mushy zone is relatively narrow, and exists through out casting. As the temperature difference increases the dendrite matrix solidify as casting drops to the solidus line for the given alloy composition.

Metals having the higher melting points favour the formation of the dendrites composition in the solidification of alloys.

Composition imbalance can be seen in dendrites growth depending upon the segregation of the elements as shown in figure.



→ Grain Structure in an Alloying Casting Showing Segregation of Alloying Components in the Centre of Casting.

The segregation is of two types,

(a) Microscopic Level
(b) Macroscopic Level

Microscopic level: Composition varies throughout each individual grain. Each dendrite has a higher portion of one of the elements in the alloy.

Macroscopic level: Composition varied throughout the casting as the regions of the casting freeze first and richer in one component than the other.

Risers:

Riser is a hole cut in the cope to permit the molten metal to rise above the highest point in the casting. The riser is a passage of sand made in the mould during ramming. The molten metal raises in the riser after the mould cavity is filled up.

Functions of riser:

(i) It enables the pourer to see the metal in the mould cavity. If the metal is not seen in the riser, it indicates that either the metal is not sufficient to fill the mould cavity or there is some obstruction to the metal flow between the sprue and riser.
(ii) The riser gives passage to the steam, gas and air from the mould cavity while filling the mould with the molten metal.
(iii) It serves as feeder to feed the molten metal into mould cavity to compensate for its shrinkage.

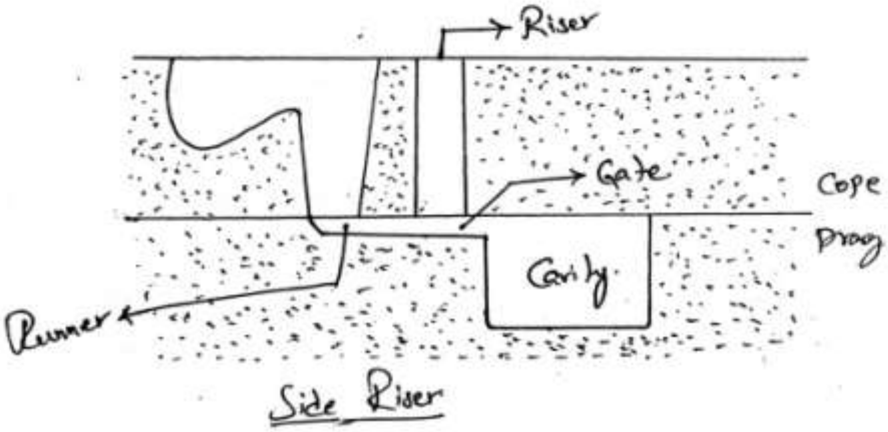
Riser Location:

Before the shape and size of the riser is determined, its location must be specified. Any casting, no matter bow complex, can be subdivided into several geometrical shapes, consisting of two heavier sections joined by a thinner section. A riser should be located close to each heavier section. Also it should be located in such a manner that it is the last portion of the casting to solidify.

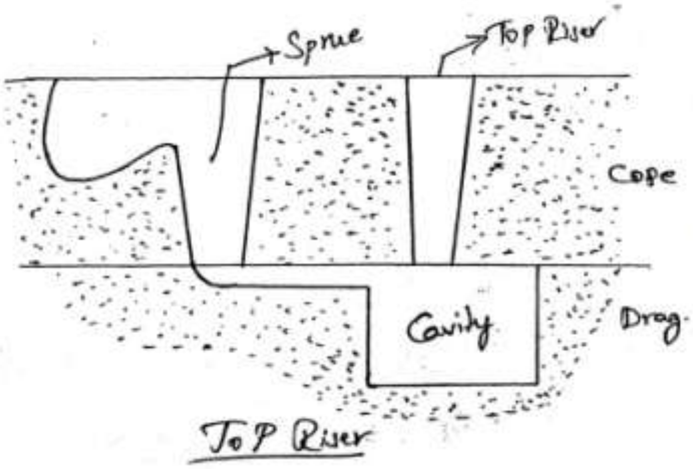
Types of Risers:

Depending upon its location, the riser is described as 'Top Riser' or 'Side Riser'.

Side Risers: If the riser is located between runners and casting, it is known as side riser. It is also called a 'live or hot riser' since it is filled last and contains the hottest metal. The side riser receives the molten metal directly from the runner before it enters the mould cavity and is more effective than the top riser.



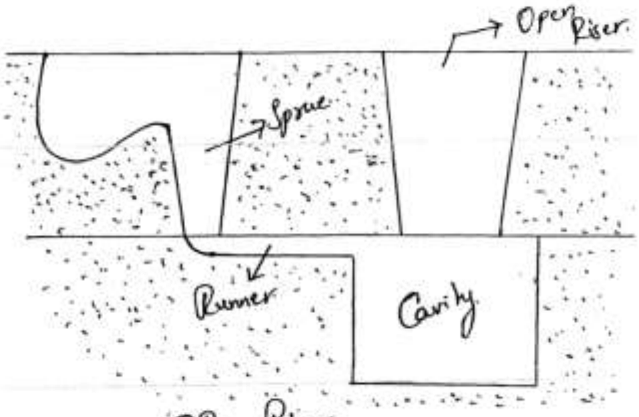
Top Risers: If a riser must be placed at the top of the casting or at the end of the mould cavity then it is called as Top riser or 'dead or cold riser'. These types of risers fill up with the coldest metal and are likely to solidify before casting.



Open risers: These risers are open to the atmosphere at the top surface of the mould.

Advantages:

(i) It can be easily moulded.
(ii) As it is open to atmosphere, it will not draw metal from the casting as a result of partial vacuum in the riser.
(iii) These risers serve as collectors of nonmetallic inclusions floating up to the surface.



Open Riser

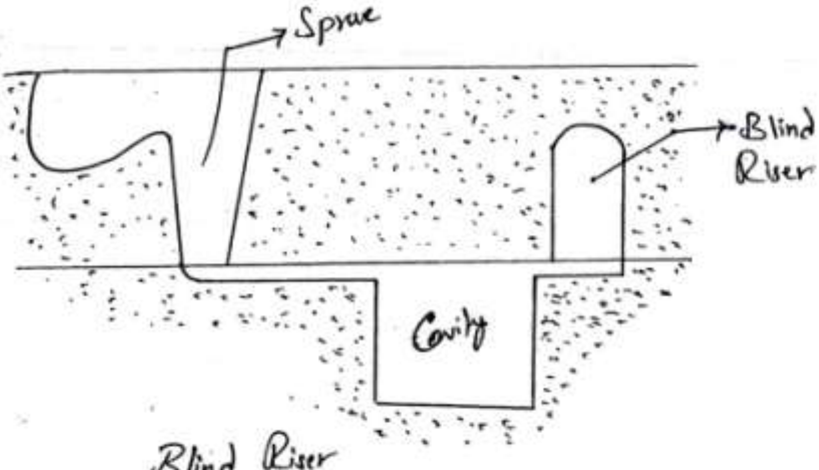
Limitations:

(i) They can be moulded only in the cope i.e., either at the top of the mould cavity or on the side at the parting line.
(ii) Open risers are holes through which foreign matter may get into the mould cavity.

Blind Risers: A riser which does not break to the top of the cope and is entirely surrounded by moulding sand is known as 'Blind Riser'. Blind risers are setup in high moulding boxes, where the use of open risers would entail a large consumption of molten metal.

Advantages:

(i) Considerable latitude or flexibility is allowed for positioning the riser, either in a cope or in a drag.
(ii) It is surrounded on all sides by moulding sand. Thus it looses heat slowly which helps in better directional solidification of the casting.
(iii) A blind riser can be smaller than a comparable open riser, there fore more yield is obtained.



Blind Riser

The main drawback of the blind riser is that when the metal in it cool, metal skins may quickly form on its walls. This will result in a vacuum in the riser and the riser will not feed and may actually draw metal from the casting.

Shape and size of Riser: The risers are designed to solidify last so as to feed enough metal to heavy sections of the casting to make up for the shrinkage before and during solidification. For this they should loose heat at a slower rate. Amount of heat content is proportional to the volume and the rate of heat dissipation depends upon the surface area of the riser. Thus the risers should be designed with a high V/A (Volume/Surface Area) ratio, for a given size. This will minimize the loss of heat, so that the riser will remain hot and the metal in the molten state as long as possible.

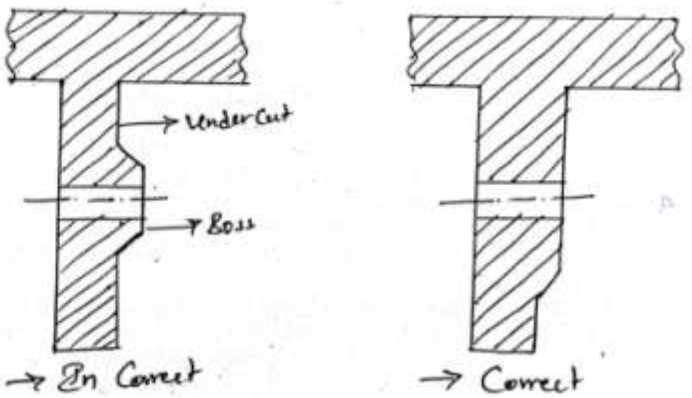
This condition can be met when the riser is spherical in shape so that its surface area is minimum, for a given volume. The next best practical shape is a cylinder. Rectangular sections are very inefficient and must be avoided as far as possible. As risers of ideal spherical shape are difficult to mould, consequently the cylinder is probably the best shape to employ for general run of casting.

Casting Design Considerations:

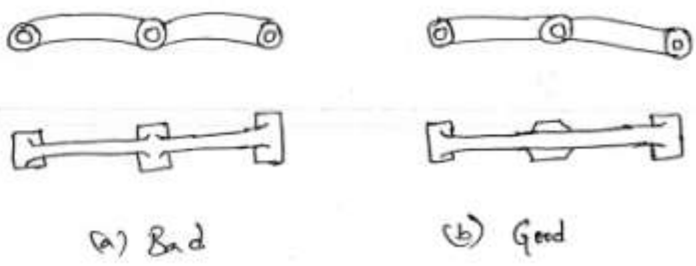
A cast part must have such a design as to ensure a high level of its working characteristics like strength, rigidity, stiffness, tightness, and corrosion resistance at a given mass and shape of the part. Proper attention to design details can minimize casting problems and lower costs. For this a close collaboration between the designer and the foundry engineer is important.

The main feature of the casting process is that the molten metal poured into the mould contracts as it cools and solidifies. The main consideration is that the shape of the casting should allow for directional solidification. Some of the important design considerations are discussed below:

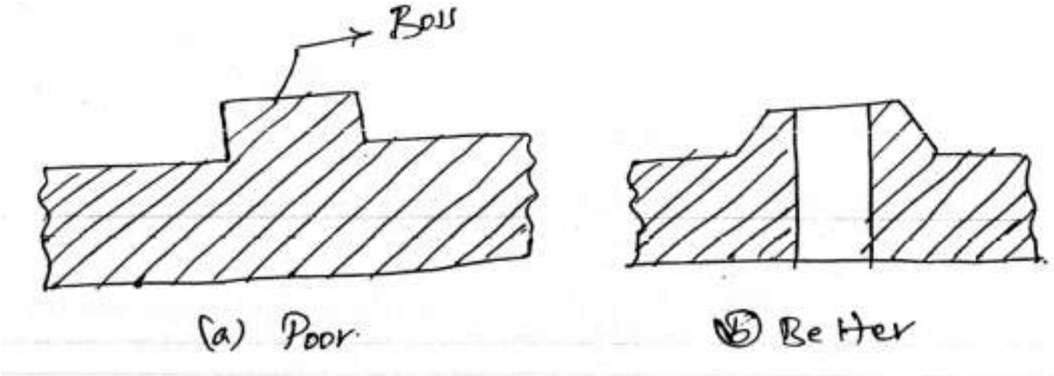
a. The shape of the castings should be as simple as possible. That helps to reduce the cost of patterns, cores and moulds.
b. Castings should be made as compact as possible. Large steel castings of complex shape are divided into two or more castings, which can be easily cast, and then joined by welding to produce a 'cast-weld' construction.
c. Projecting details (bosses, lugs etc…) or undercuts should be avoided, or the pattern elements for them should be made so that they do not hinder the removal of pattern from the mould.



d. To facilitate removal, provision should be made for draft (1/2° to 3°) on the castings vertical surfaces. The draft is greater for the inside surfaces than for the exterior surfaces.
e. Where ever possible, avoid complex parting lines on the pattern, because these increase the cost of moulding operations. Parting lines should be in a single plane, if practicable. The design (b) is better not only because the lines are simpler and the pattern is less costly but also because a plane parting can be used in the process of moulding.



f. Avoid concentration of metal so that no shrinkage cavities are formed. For this reason, bosses, lugs, pads should be avoided unless absolutely necessary. Metal section is too heavy at bosses which are difficult to feed solid.



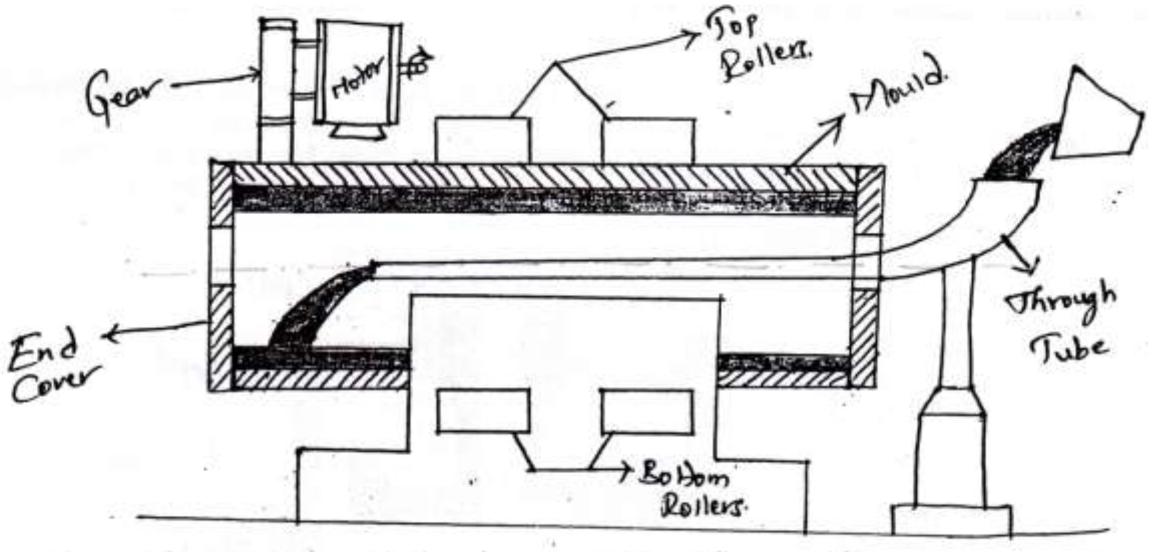
g. The position of the castings surfaces during metal pouring must be taken into account, since gas blow holes may form on the castings upper horizontal surfaces. Critical surfaces of castings should lie at the bottom part of the mould.
h. Minimum Section Thickness: The thickness of the casting walls is determined depending on the size and mass of the casting, its material and the mass of the casting. Except for cast iron, the minimum section thickness depends mainly upon the fluidity of the molten metal. If a casting section is too thin, or if it is relatively thin and extends too far, a misrun or cold shut defect will occur.
i. The casting design should provide for easy removal of core materials and reinforcements and should make for ease of cleaning and fettling after the shake out operation. In order to remove core material from internal cavities, special bosses with holes should be provided on the casting. After the cleaning, the holes are stopped with plugs. The outer contour of the casting should be free of deep blind pockets and recesses. The cavities should have openings of sufficient size to facilitate stripping.
j. A material that has a large solidification shrinkage will result in hot shortness if the moulding material does not collapse sufficiently to allow shrinkage or the moulds should be of simple shape so as not to develop tensile stress during solidification. If possible the casting design should be changed to allow deformation without moving large mould masses.

Special Casting Processes:

Centrifugal Casting Process: Centrifugal casting is the method of producing castings by pouring the molten metal into a rapidly rotating mould. The metal is thrown out towards the mould face by the centrifugal force under considerable pressure.

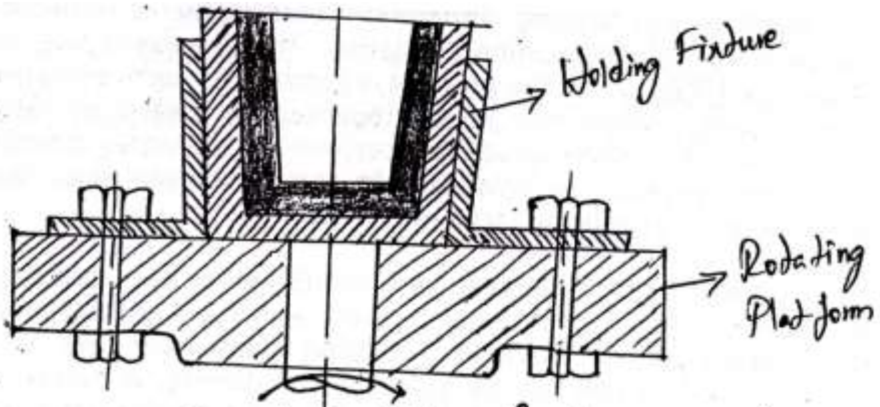
According to the shape of mould, the centrifugal casting method can be classified as:
1. True centrifugal casting Process
2. Semi centrifugal casting Process
3. centrifuging casting Process

1. True Centrifugal Casting Process : In this process, the axis of rotation of the mould coincides with the axis of the casting and the molten metal is pushed outwards because of the centrifugal force, no core is required for making the concentric hole. The axis of rotation may be horizontal, vertical or inclined. The most commonly cast parts are cast iron pipes, liners and cylindrical barrels. The mould may be permanent type or sand lined mould. A normal centrifugal casting machine used for making cast iron pipes in sand moulds is shown in below fig.



True Centrifugal Casting Process (Horizontal Mould)

The moulding flask is rammed with sand to confirm to the outer contour of the pipe to be made. At the end of the mould is fitted with a gear which meshes with a gear on a motor driven shaft. The ends of the hollow mould are partially covered by covers which can be detached when the casting is to be pushed out of the mould. At both end covers, a central hole is provided. From one side, the molten metal is poured, from a ladle and from other the hot gases escape out.



True Centrifugal Casting (Vertical Mould).

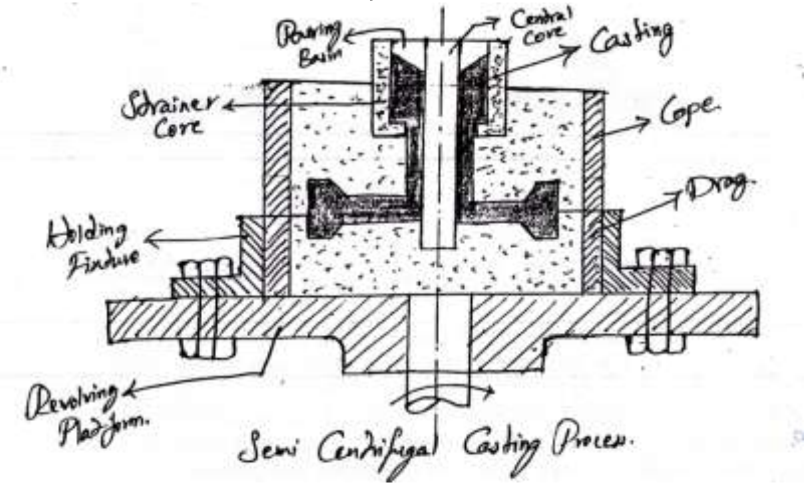
Advantages:
1. The inclusions get segregated towards the centre and can be easily removed by machining.
2. The casting has better mechanical properties.
3. No central core is required.
4. No gates and risers are required.
5. The process is used for making pipes, hollow shafts, bushes and similar parts with a concentric hole.

Limitations:
1. This method is limited to certain shapes with axis symmetric.
2. Equipment is costly.

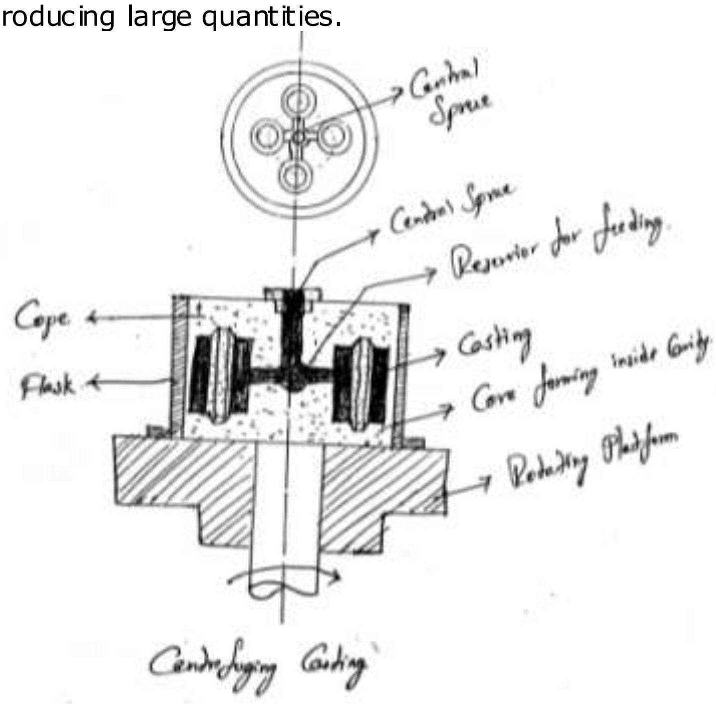
Applications: Cast iron pipes, alloy steel pipes, liners of I.C. engine.

2. Semi centrifugal casting Process: Semi centrifugal casting is used for producing parts which are more complicated than true centrifugal casting i.e., gear blanks, wheels, pulleys etc… It is not necessary that to have a central hole in the parts. Even core can also be used.

The moulds are made of either sand or metal. The moulds are rotated about a central vertical axis which is concentric with axis of sprue (as shown in fig). Rotational speed in this process is usually lower than for true centrifugal castings. The molten metal is poured through central pouring basin. For producing large quantity the use of stacked moulds are quite economical.



3. Centrifuging casting Process: Centrifuging is used to obtain higher metal pressure during solidification of casting. The process is used to produce castings of almost any shape, but the process is suitable for only smaller castings. A number of small mould cavities are joined together by means of radial runners which are connected to a central sprue. The cavities are uniformly placed over the periphery so that their masses are balanced. In this processes also, stack moulds are quite economical for producing large quantities.



The difference between true centrifugal or semi centrifugal and centrifuging is that in case of true centrifugal or semi centrifugal casting process is that the axis of mould coincides with the axis of rotation where as in case of centrifuging the axis of rotation and the axis of the mould are not same. A number of mould cavities are arranged on the circumference of circle and are connected to a central down sprue through radial gates. This is suitable for only small jobs of any shape.

Die Casting Processes:

Die Casting processes is closely related to permanent mould casting processes; in both processes reusable metallic moulds (dies) are used. In die casting process metal is forced under pressure compared to permanent mould casting (in permanent mould casting molten metal flows using simple gravity flow). Because of high pressure involved in die castings, narrow section and complex shaped can easily be produced. Moreover smoother casting surfaces and closer tolerances can be achieved since no coating is applied to die cavities.

The die casting machine consists of two halves with vertical parting. One half is called cover die which is stationary and fixed to the machine. The other half is called ejector die which moves for opening and closing. The die halves are having dowel pin and dowel holes to maintain proper alignment. The die casting machine performs the following functions:

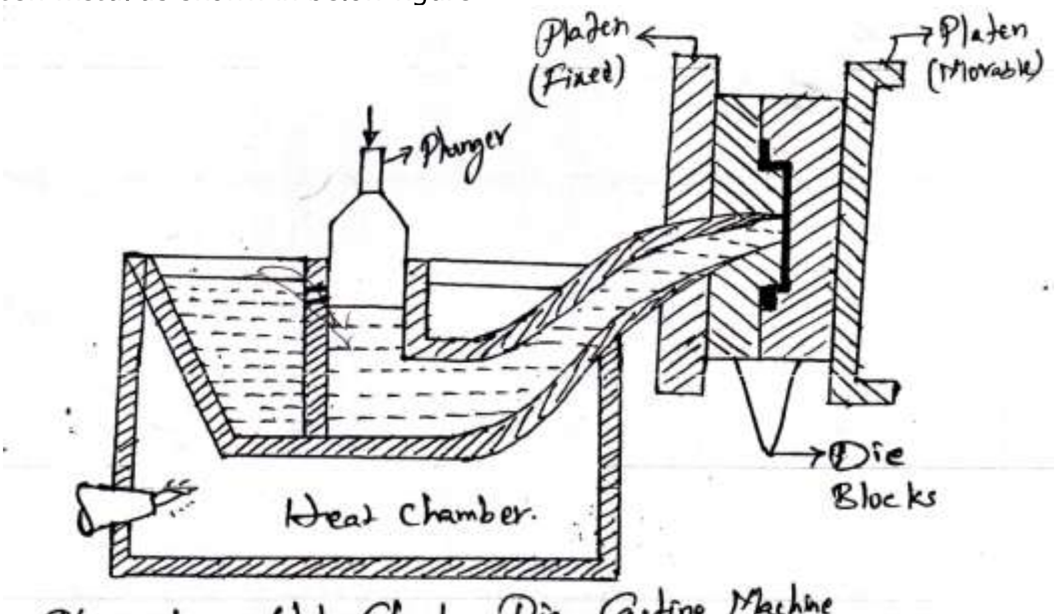
(i) Cycle starts when both dies are apart. Lubricant is sprayed on die castings manually or by auto lubrication system.
(ii) The two die halves are closed and clamped. Dies can be closed and clamped by hydraulic or mechanical mechanism.
(iii) Molten metal is injected into closed dies under pressure. Pressure is maintained during solidification.
(iv) The dies are forced opened.
(v) Casting is ejected from dies along with its attached sprue and runners.

There are basically two types of die casting machines:

(i) Hot Chamber Process
(ii) Cold Chamber Process

The main difference between the two types is that in hot chamber, machine itself contains furnace for liquid metal where as in cold chamber process metal is melt in separate furnace and then poured into die casting machine with help of ladle for each casting cycle. Let us discuss these processes in some what more details.

(i) Hot Chamber Process: This is also called sometimes known as "submerged plunger die casting process". In hot chamber die casting machine, there is suitable furnace for melting and holding the metal. A plunger is submerged in reservoir of molten metal as shown in below figure.



Plunger type Hot Chamber Die Casting Machine

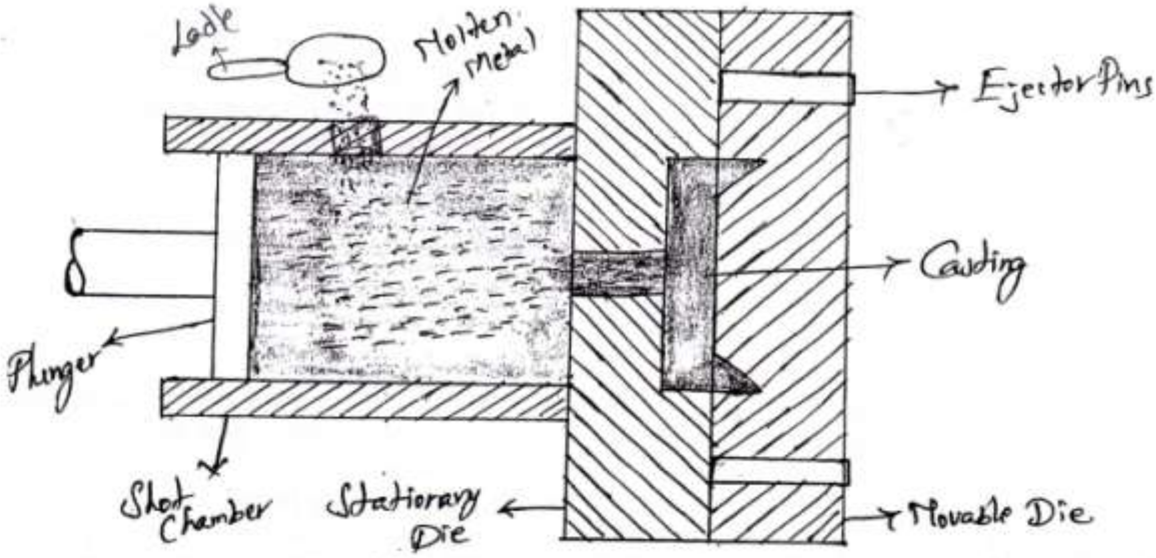
Following are the steps in a casting cycle.

1. As the plunger is raised, opening of cylinder is uncovered and, molten metal enters the cylinder from molten metal reservoir under the force of gravity.
2. The plunger is forced downward, pneumatically or hydraulically, closing the cylinder opening and forcing the molten metal through a nozzle in die.
3. As soon as casting is solidified, the pressure is relieved, dies are opened and casting is ejected by means of knockout pins. As the same time plunger again moves up uncovering the holes in cylinder and allowing the liquid metal from furnace to cylinder.

The cycle timings and pressure in the machines are set to suit the different metals and castings. The added advantage of hot chamber process is that molten metal is injected from the same chamber, in which it is melted, i.e., there is no handling of molten metal. The limitation of process is that it cannot be used for higher melting point metals. The process can be used for most of low melting temperature alloys such as zinc, lead and tin.

(ii) Cold Chamber Process: The hot process is suitable for low temperature melting alloys. As cylinders is continuously in contact with liquid metal, aluminium and other high temperature melting alloy will attack the cylinder material. So for these metals cold chamber process is used. In cold chamber processes, holding furnace foe liquid metal is not integral with die casting machine. The metal is melted in a separate furnace and then poured into die casting machine with the help of ladle. This process reduces the contact time between liquid metal and shot chamber.

The cold chamber process is shown in below figure.



Cold Chamber Die Casting Process

The cycle starts when,

1. Lubricants are sprayed throughout the dies.
2. Die halves are closed and clamped.
3. Measured quantity of molten is poured in shot chamber of the machine. The metal can be poured either by hand ladle or by means of auto ladle is form of robotic device.
4. Plunger forces the metal into die cavity and maintains the pressure during solidification.
5. Dies are open and casting is ejected.
6. Plunger returns to original position completing the cycle.

Since molten metal is transferred through ladle, cold chamber process has a longer operating cycle than that of hot chamber process. Also during the transportation of liquid metal from furnace to die casting machine, it may loose the super heat and some times may cause defects such as cold shuts.

Advantages of Die Casting Processes:

1. Closer dimensional tolerance and smoother casting surfaces can be achieved since not coating is applied to die casting.
2. Because of high pressure involved in die casting narrow sections and complex shapes can easily produced.
3. Very high production rates can be achieved.
4. Complex casting can be produced because of using the movable cores.
5. Die casting gives better mechanical properties because of fine grained skin formed during solidification.
6. The process is very economical for large scale production.

Limitations of Die Casting Processes:

1. The dies and machines are very costly. Therefore economy in production is possible only when large quantities are produced.
2. Not suitable for all materials because of die materials limitations. Normally non ferrous metals like Zn, Mg, Al or Copper alloys are die cast.
3. Maximum size of casting is limited. Normally castings weighing between 4 kg to 15 kg are cast because of machine limitations.
4. The air may get entrapped during the process. It is a usual problem with die castings.

Investment Casting Processes:

These methods are called as "Precision" because the castings obtained by these methods have very smooth surfaces and posses high dimensional accuracy. The term "Investment" refers to the layer of refractory material with which the pattern is covered to make the mould. Like sand casting method, the mould is destroyed every time a casting is made.

The two common and widely used methods under this category are ,

(i) Lost – Wax Method
(ii) Shell – Moulding Method

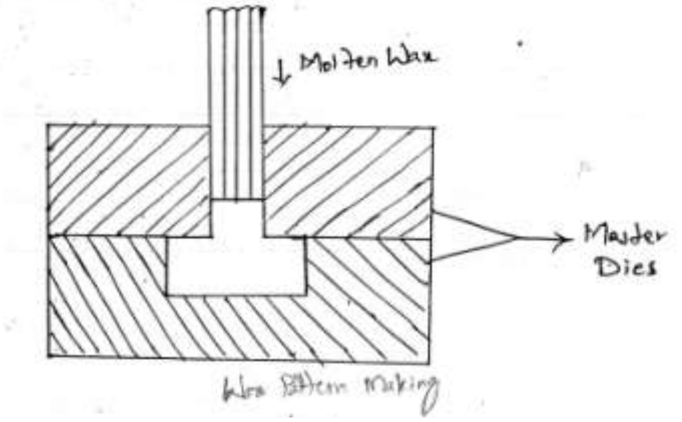
(i) Lost – Wax method: The Lost – Wax method is also called simply as 'Precision – investment casting' has been used for many years by jewelers and dentists. Basically the method involves the use of expandable pattern surrounded with a shell of refractory material to form the casting mould. Castings are formed by pouring molten metal in the mould cavities created by melting out the pattern. Since the pattern made of wax is melted out and gets destroyed, that is why the name "lost – wax method".

The steps involved in this method are explained below:

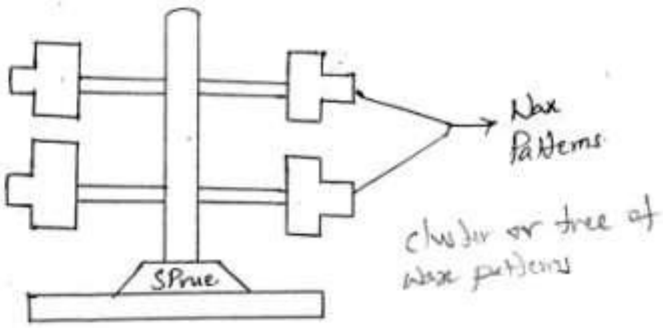
1. Making a master pattern of the part to be cast. The pattern is usually made of a metal that can be easily machined, such as brass, aluminium alloy or steel, or a fusible alloy. It is made to compensate for wax and metal shrinkage.

2. Making a composite die to the master pattern for casting the wax/plastic patterns. The die material is a low melting point alloy like bismuth alloys or even aluminium. It can be made directly from die blocks of steel by machining the cavities.

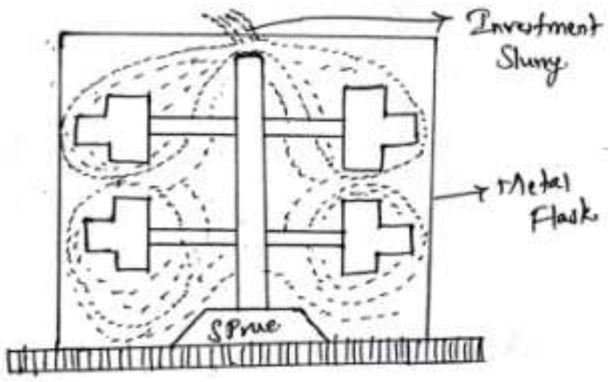
3. Making of wax/plastic patterns. For this the two halves of the matter die are clamped together and molten wax/plastic is injected into the die cavity under pressure. The molten wax is slightly above its melting point and the injection pressure is about 4 bars with the dies preheated to about 65°C.



4. Assembling the wax pattern to a gating system. Several small wax patterns are assembled together to a wax gating system connected to a central sprue, by wax welding with the aid of heated tools. In this manner, a cluster or tree of wax patterns is formed.



5. Investing the wax patterns. The wax patterns are invested in two stages. Firstly a thin coating about 1 mm of primary investment slurry is made around the wax patterns by dipping these in the slurry. This slurry is made by mixing extremely fine silica sand with a water/ethyl silicate or gypsum solution. After this primary coating has dried, the final investment moulds is done.



This final investment may be either solid type or shell type. A solid type mould is formed by placing a metal container type flask over the cluster of patterns and then pouring a hard setting moulding material into the flask. Shell type investment moulds are made by dipping the cluster of patterns in ceramic slurry and the procedure is repeated until the required thickness of mould or shell is obtained.

6. Melting out the wax patterns and baking the mould. The finished mould is dried in air for 2 to 3 hours and then baked in an oven for 2 hours to melt out

the wax. At a temperature of 100 to 120°C, the wax melts and the moulds are inverted so that all or most of the wax will run out through sprue.

7. Melting the metal and pouring the mould. The mould or flask is transferred to a drying furnace where it is first held at 150°Cand then gradually heated to 800to 900°C. This will vaporize any remaining wax in the mould. Then the preheated mould is poured with molten metal which fills the cavity and is allowed to cool and solidify.
8. After cooling the fragile mould material is broken away freeing the castings. The gates and runners are removed in the normal way.
9. Cleaning and inspecting the casting.

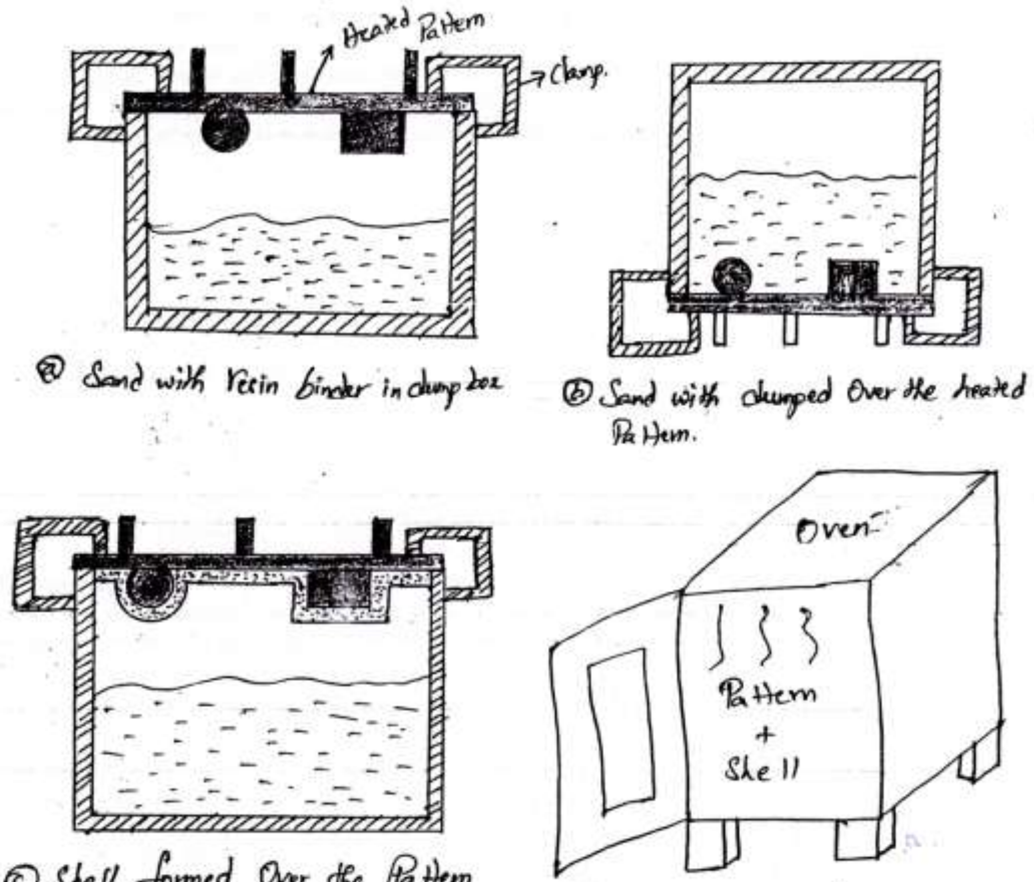
Advantages of Lost – wax method:

1. Intricate details can be cast.
2. Undercuts and other shapes, which would not allow, the with drawl of a normal pattern are easily obtained.
3. The surface is very smooth and there is no parting line.
4. High accuracy can be obtained so that much of complicated and costly machining can be eliminated.
5. Unmachinable alloys can be cast.
6. Mora than one casting can be made at a time.

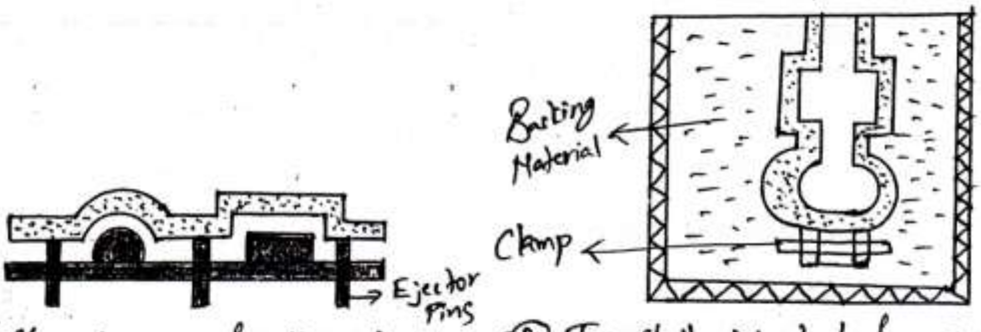
Limitations:

1. The process is involved and thus expensive.
2. The process has the limitations in use of and location of holes.
3. The parts are limited in size to a few Kg.

(ii) Shell – Moulding Method: It is a modification of the sand mould process. In this process, the mould is made up of mixture of dried silica sand and phenolic resin, formed into a thin half mould shells which are clamped together for pouring metal.



ⓐ Sand with Resin binder in clamp box
ⓑ Sand with clumped Over the heated Pattern.
ⓒ Shell formed Over the Pattern
ⓓ Shell is Curred in Oven.



(e) Shell removing from the pattern (f) Two shells joined to form a mould

Shell Moulding Process

The sand is first mixed with either urea or phenol formaldehyde resin in a muller. Metal pattern is heated to 205 to 230°C in an oven and sprayed with silicon grease and kept on the top of the dump box. The dump box contains sand mixed with thermo plastic resin. The box is inverted, causing the sand mix to fall on the hot pattern. The resin melts and flow in between the grains of sand, acting as a bond. After 30 seconds, a hard layer of sand is formed over the pattern. Then the dump box is inverted back to its original position. The pattern with a thin shell is cured for two minutes at 315°C. The shell is finally removed from the pattern by ejector pins. The two shells are clamped together to form the mould and placed in the flask with backing sand.

Advantages:

1. High dimensional accuracy and good surface finish.
2. The chances of blow holes or pockets are reduced since the shells are highly permeable.
3. Thin wall sections can be produced.
4. Shells can be stored for long time.

Disadvantages:

1. The metal patterns are costly than wood pattern.
2. Resin is an expensive binder.
3. Specialized equipments are to be used.

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UNIT 2 – Joining Processes

- **Welding Process**
- **Welding**
- **Classification of Welding Processes**
- **Types of Welds**
- **Types of Welded Joints**
- **Edge Preparation for Welding**
- **Welding Techniques**
- **Design aspects of Weld Joints**
- **Gas Welding**
- **Arc Welding**
- **Forge Welding**
- **Resistance Welding**
- **Thermit Welding**
- **Cutting of Metals**
- **Oxy – Acetylene Gas Cutting**
- **Plasma Arc Cutting**
- **Soldering**
- **Brazing**
- **Heat Affected Zones in Welding**
- **Welding Defects**
- **Testing of Welds**
- **Destructive and Non-destructive testing**
- **Comparison between welding, soldering & brazing**

Welding Process:

Welding is a metal joining process in which fusion is obtained by application of heat and r pressure. Combination of these two variables may be high temperature with no pressure, high pressure with no rise in temperature or both high temperature and pressure. Welding is an atomic bonding process and metallurgical bond is accomplished by attracting forces between atoms. One beauty of welding process in comparison to other processes is that by this process we can have strength of joint equal and sometime greater than the parent metals. This makes welding one of the most extensively used manufacturing process.

Welding is extensively used in automobile industry, aircraft machine frames, structural work, tank repair work, ship building, etc. It is also useful method for repairing of broken castings and defective metal parts.

Welding:

There are many definitions of a welding process. But the most comprehensive is given below:

Welding is defined as "a localized coalescence of metals, where in coalescence is obtained by heating to suitable temperature, with or without the application of pressure and with or without the use of filler metal. The filler metal has a melting point approximately the same as the base metals".

The welding process is metallurgically join together two metal pieces, to produce essentially a single piece of metal. The process results in what is known as a 'Permanent joint'. A good welded joint is as strong as the parent metal. The product is known as 'Weldment'.

Advantages: The wide spread use of welding at the present time is due to its following advantages:

1. Welding results in a good saving of material and reduced labour content of production.
2. Low manufacturing costs.
3. Dependability of the medium, that is, the weldments are safer.
4. It gives the designer great latitude in planning and designing.
5. Welding is also useful as a method for repairing broken, worn or defective metal parts. Due to this, the cost of reinvestment can be avoided.
6. Without welding techniques, the light weight methods of fabrication, so vital to the automotive and aircraft industries, would be unthinkable.

The welding process has the plus points that it is readily adaptable to streamline structure and the welded joints are very tight. Welded joints are strong, especially under static loading. However they have poor fatigue resistance due to stress concentration, residual stresses and various weld defects, such as cracks, incomplete fusion, slag inclusions and the like. But all these drawbacks can be overcome to a large extent.

The drawbacks of welding can be: Not all metals are satisfactorily weldable and the weldments are less readily machinable, as compared to castings.

Classification of welding processes:

Welding processes may be classified according to the source of energy employed for heating the metals and the state of metal at the place being welded. These may be divided into two groups as follows:

(a) Pressure Processes: In this processes the parts to be joined are heated to a plastic state (fusion may occur to a limited extent) and forced together with external pressure to make the joint.

Some of the more common processes in this group are mentioned below:

1. Forge Welding
2. Thermit Pressure welding
3. Pressure Gas welding
4. Electric Resistance welding

(b) Fusion processes: In these processes, the material at the joint is heated to the molten state and allowed to solidify to make the joint, without the application of pressure. Here some joints may be made without the addition of a filler metal, but in general, a filler metal must be added to the weld to fill the space between the parts being welded. The filler metal deposited should ordinarily be of the same composition as the base metal.

Some of the common welding processes in this group are listed below:

1. Gas welding
2. Electric Arc welding
3. Thermit Fusion welding

The welding processes can also be classified as:

Autogeneous: In 'Autogeneous' processes, no filler metal is added to the joint interface, for example, cold and hot pressure welding processes and electric resistance welding.

Homogeneous: In 'Homogeneous' processes, filler metal is added and is of the same type as the parent metal, for example, welding of plain low C steel with a low C welding of 70 – 30 brass with a 70 – 30 brass welding rod etc.

Hetrogeneous: In 'Hetrogeneous' processes, a filler metal is used but is of a different type from the parent metal, for example, brazing and soldering processes. Brazing and soldering are not strictly the welding processes in view of the definition of welding process given above. However these processes also belong to the family of welding processes.

The two most widely used welding methods are: Gas welding and Arc welding.

The welding processes are classified as follows:

1. Gas Welding
   (a) Oxyacetylene Welding (b) Oxyhydrogen Welding

2. Arc Welding
   (a) Carbon Arc Welding (b) Metal Arc Welding
   (c) Submerged Arc Welding (d) Inert Gas Welding
   (e) Plasma Arc Welding (i) TIG (ii) MIG
   (f) Electric Slag Welding

3. Resistance Welding
   (a) Spot Welding (b) Seam Welding
   (c) Projection Welding (d) Butt Welding

4. Solid State Welding
   (a) Friction Welding (b) Ultrasonic Welding
   (c) Explosive Welding

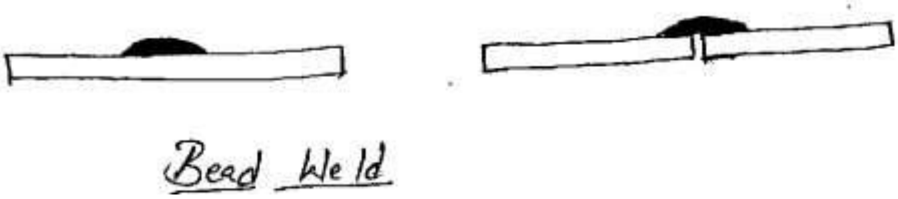
5. Thermo Chemical Welding
   (a) Thermit Welding (b) Atomic Hydrogen Welding

6. Radiant Energy Welding Process
   (a) Electron Beam Welding (b) Laser Beam Welding

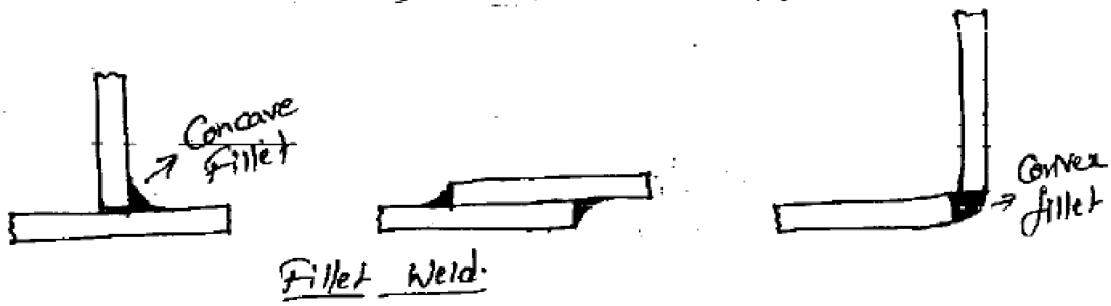
Types of Welds:

The following are the different types of welds used in making a joint.

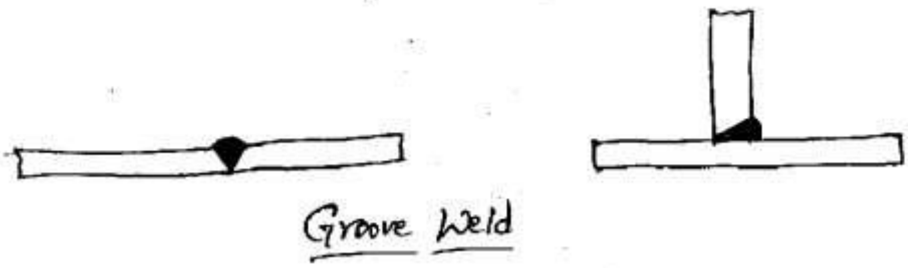
(i) Bead Weld: A 'Bead' weld is one in which the filler metal is deposited at a joint where the two surfaces adjoining the joint are in the same plane. A 'Bead' is defined as a single run of weld metal. The below figure shows the type of bead weld.



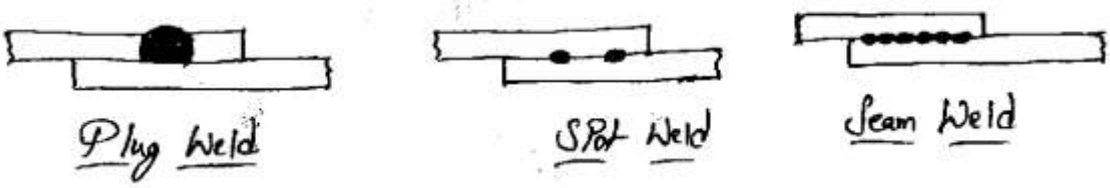
(ii) Fillet Weld: A 'Fillet' weld is one in which the filler metal is deposited at the corner of two intersecting surfaces, such as T or Lap joint.



(iii) Groove Weld: A 'Groove' weld is one in which the filler material is deposited in a groove formed by edge preparation of one member or of both the members.



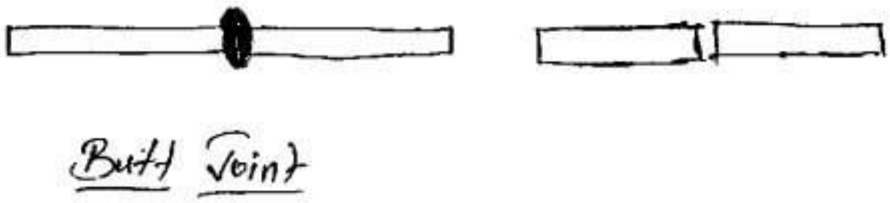
(iv) Plug or Slot Weld: A 'Plug' or 'Slot' weld is one in which a hole is formed through one of the pieces to be welded and the filler material is then deposited into this hole and fused with the mating part.



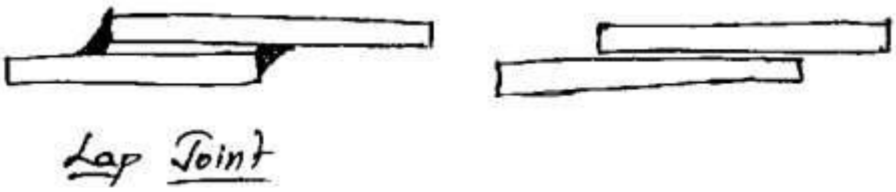
Types of Welded Joints:

The relative positions of the two pieces being welded determine the type of joint. There are five basic types of joints which are used in fusion welding. These are,

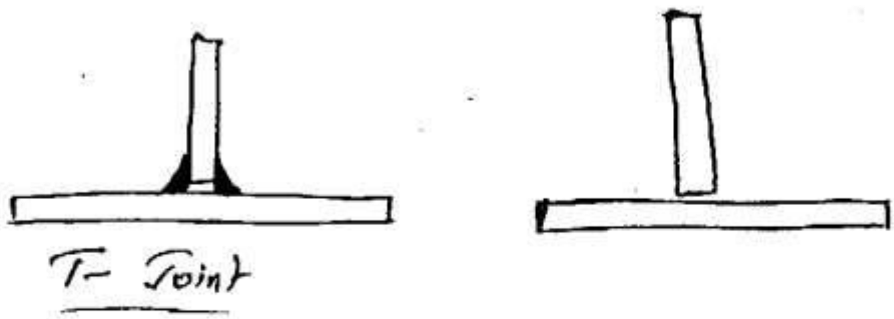
(a) Butt Joint: The butt–joint is used to join the ends of two plates or surfaces located approximately in the same plane.



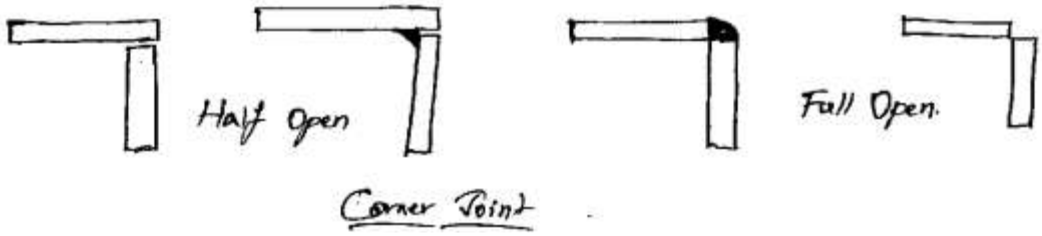
(b) Lap Joint: The lap-joint is used to join two overlapping plates so that the edge of each plate is welded to the surface of the other.



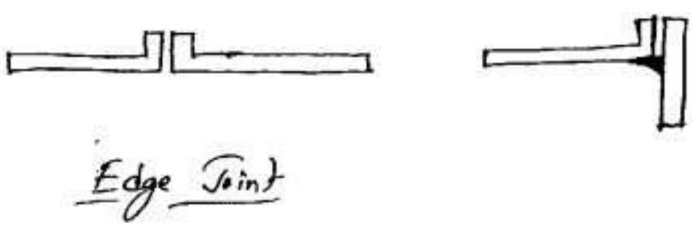
(c) T – Joint: The T-joint is used to weld two plates or sections whose surfaces are at right angles to each other.



(d) Corner Joint: The corner-joint is used to join the edges of two sheets or plates whose surfaces are at 90° to each other.



(e) Edge Joint: The edge joint is used in joining the sheet metal work.



Edge Preparation for Welding:

The preparation of the edges of the pieces to be welded depends upon the thickness of metal being welded. Edge preparation is necessary when thickness increases so that heat would be able to penetrate the entire depth. This ensures formation of sound welds. The edge preparation is done by beveling the edges of the pieces after the rust, grease, oil or paint are completely removed from their surfaces.

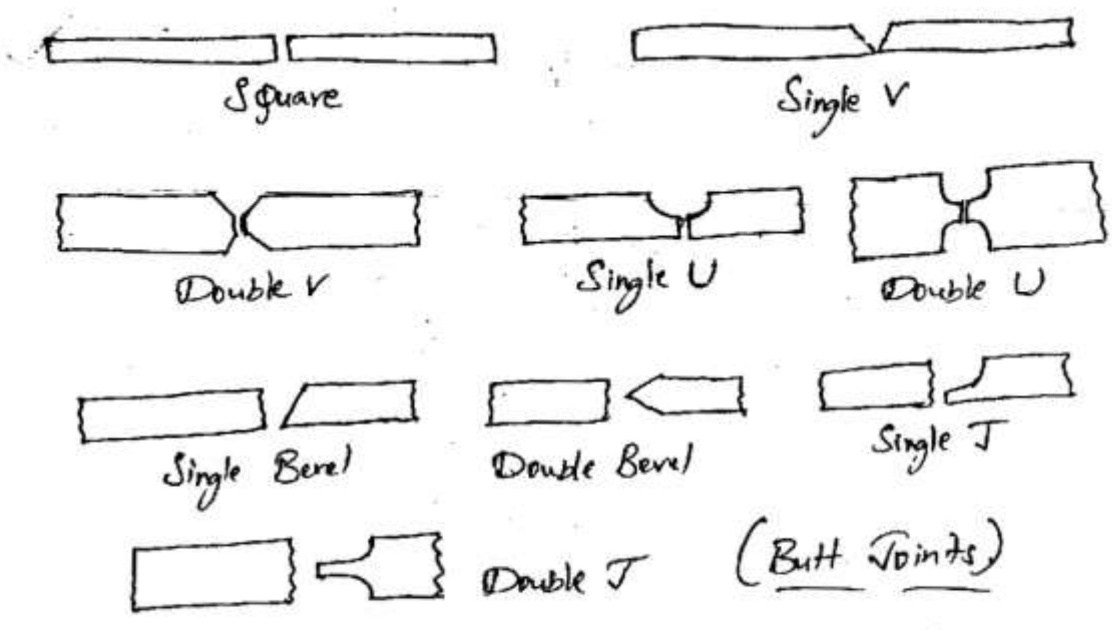
There are five basic types of chamfers put on the mating edges prior to welding; they are Square, V, Bevel, U and J.

These five basic types of edge preparation are applied to the different types of weld joints.

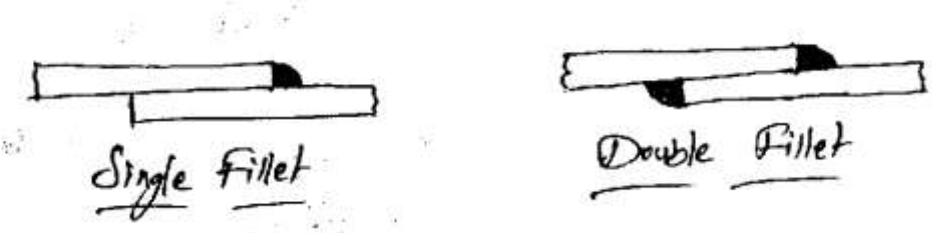
Butt joints: The straight square butt joints with no special edge preparation are used when the thickness of the two joints to be welded is small so that heat of welding penetrates the full depth of joint. These joints are suitable from 3 to 8 mm. However, if the plate thickness is more than 4.5 mm. edge preparation is recommended.

Single V: For thickness up to 16mm
Double V: For thickness > 16mm
Single and Double U: For thickness greater than 20mm.

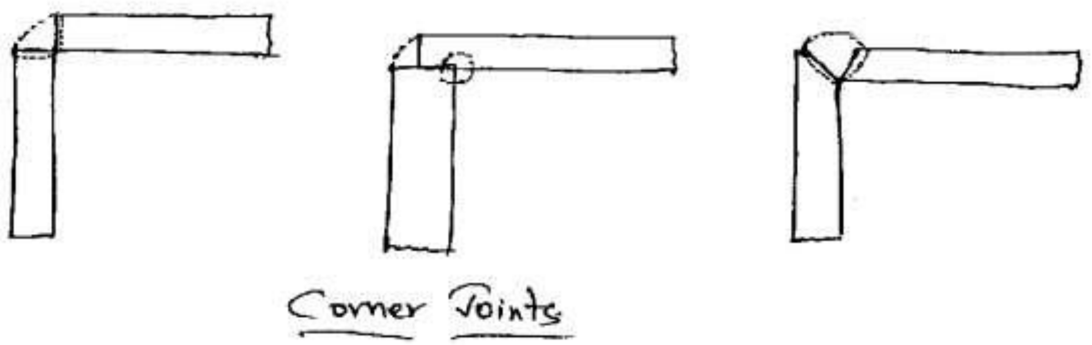
Other edge preparations for a butt joint are: Single bevel, Double bevel, Single J, Double J. Butt joints are made by bead or groove welds.



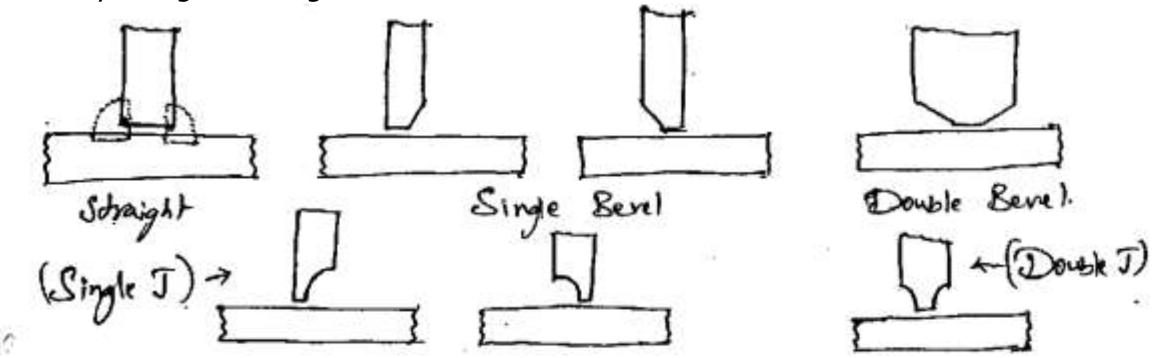
Lap Joints: These joints are used to join thin sheets, usually less than 3 mm thick. These joints do not need any special edge preparation. The joint is produced by fillet welds.



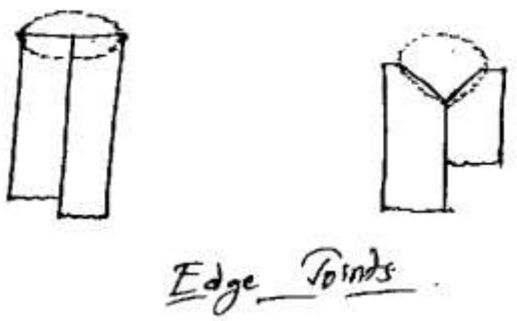
Corner Joints: These joints are used to join sheets upto 5mm thick. These joints are welded with or without edge preparation, with the help of fillet or groove welds.



Tee Joints: Only structures subjected to low static loads can be welded without edge preparation. Single bevel joints are employed for critical structures in which the members are from 10 to 20 mm thick and Double bevel designs are used for thicker metals. Single J and Double J joints can also be used thicker metals. Tee joints are made by using fillet or groove welds.



Edge Joints: Edge joints are used for metals upto 3 mm thick. The height of flange should be twice the thickness of the sheet. These joints are made by Bead or Groove welds.



Welding Techniques:

The selection of a proper technique will depend upon the metal to be welded, its thickness and the properties of the weld.

The following methods are commonly used:

(i) Position of Welding:

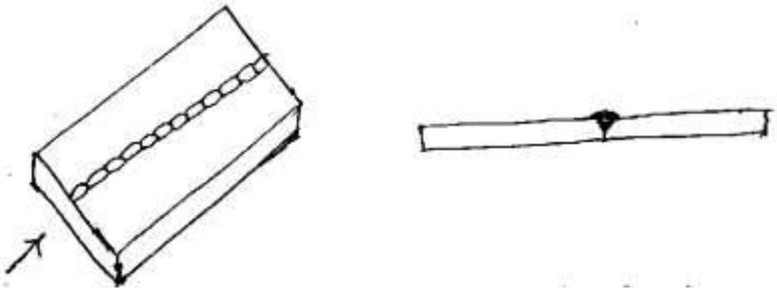
(a) Down Hand Welds (b) Vertical Welds (c) Inclined Welds
(d) Horizontal Welds (e) Overhead Welds

(ii) Direction of Travel Welding Rod and Welding Torch:

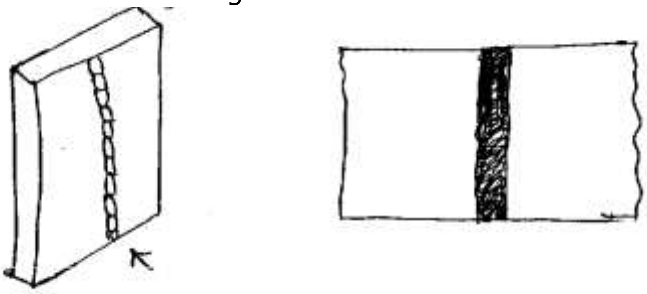
(a) Leftwards or Forwards welding
(b) Rightwards or backwards welding
(c) Vertical Welding

(i) Position of Welding:

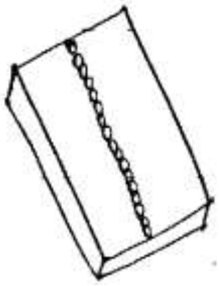
(a) Down Hand Welds (flat): These welds are deposited in any direction on a horizontal surface so that the flame is above the face of the weld.



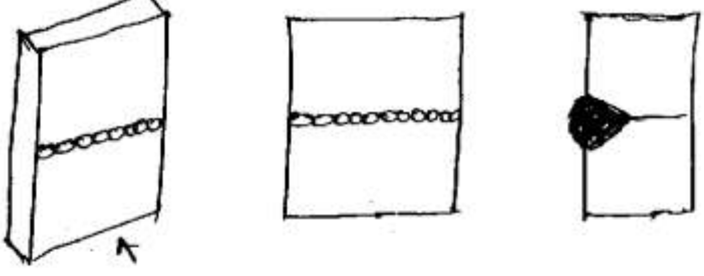
(b) Vertical Welds: These welds are deposited on a vertical surface in a vertical direction as shown in below figure.



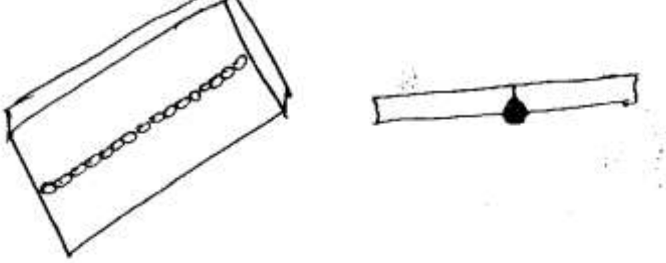
(c) Inclined Welds: These welds are deposited on an inclined surface as shown in below figure.



(d) Horizontal Welds: These welds are deposited on vertical surface in a horizontal direction as shown in fig.

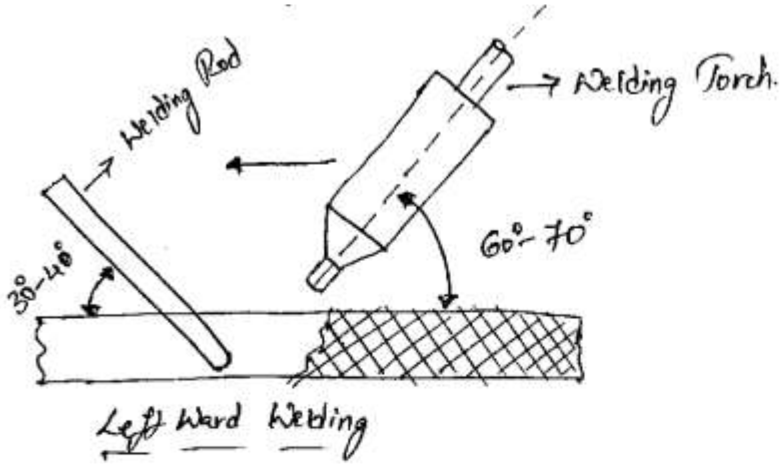


(e) Overhead Welds: These welds are deposited on a horizontal surface in any direction so that the face of welds is above the flame as shown in fig.

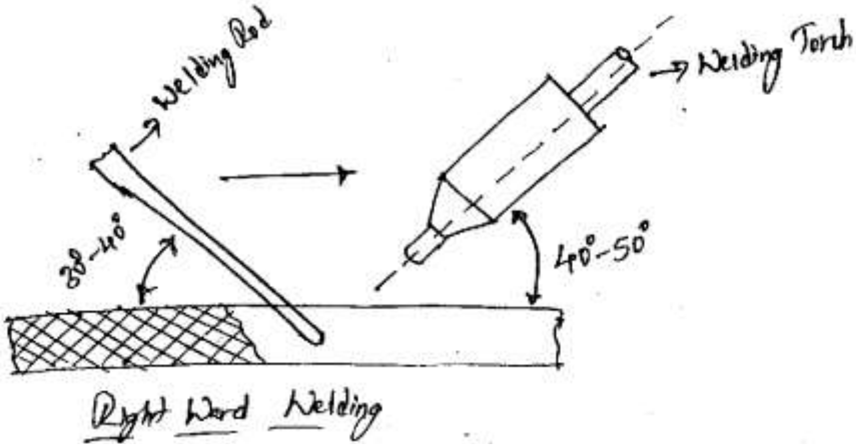


(ii) Direction of travel welding rod and welding torch:

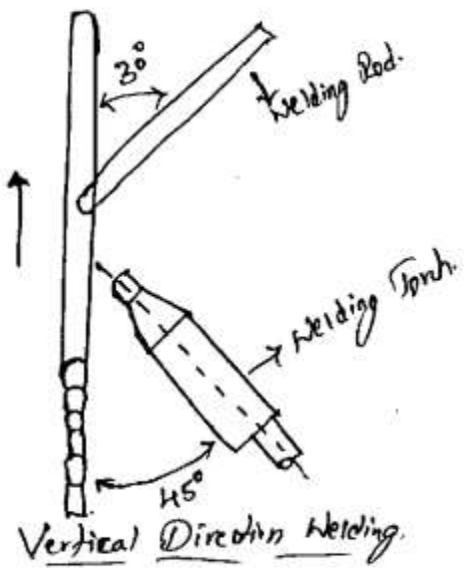
(a) Leftwards (or) Forward Welding: The welder holds torch in the right hand and filler rod in the left hand. The weld is made working from right to left as shown in below figure. Since the flame is pointed in the direction of the welding, it preheats the edges of the joint. This method is suitable for mild steel, cast iron, aluminium, brass etc…



(b) Rightwards (or) Backward Welding: It is carried out from left to right as shown in below figure. Thicker materials can be welded by this method.



(c) Vertical Welding: It starts at the bottom of the weld joint and gives an oscillating movement to the welding torch which points slightly upwards as shown in below figure.



Design aspects of Weld Joints:

The following points should be kept in mind when designing a weldment:

1. Weldments should be designed to require a minimum of weld metal.
2. Thermal contraction of metal, which has been heated by welding, may cause internal residual stresses and distortion. These can be controlled or reduced by: (a) Preheating (b) Minimum number of welds (c) Smallest size of weld that fulfills requirements (d) Maximum use of intermittent welds (e) Slow after cooling.
3. Sharp discontinuities in metal should be kept at a minimum since these cause stress concentration.
4. An important strength weld should not be located where much of it may be removed later by machining.
5. Welds should be located so that adequate strength will be provided at the proper places on a structure or part.
6. As far as possible, a straight line force pattern should be provided.
7. Laps, straps and stiffening angles should be avoided except as required for strength.
8. Lap welds and lap strap welds are not recommended for elements over 10mm thick.
9. Where ever possible, use butt joints.
10. The ends to be welded should be of equal thickness.
11. The use of welding fixtures should be avoided as far as possible.
12. Welds should not be subjected to bending.
13. A weld should not be located at the point of maximum deformation.
14. Ribs should be designed correctly and these should be used with care.
15. Provide for easy access to welds so that they are accessible for inspection.
16. Distribute heavy loading over long welds in the longitudinal direction.
17. Avoid large flat walls, which tend to bulge and flex.
18. The joint should have properly prepared grooves.
19. If alternating stresses are involved, avoid running a weld at right angles to the direction of maximum principal stress owing to the low fatigue resistance offered by welds.
20. Whenever possible, the design should provide for welding in the flat or horizontal position, not overhead.

Gas Welding:

Gas welding is a fusion welding process. It joins metals using the heat of combustion of an oxygen/air and fuel gas i.e., acetylene, hydrogen, butane mixture. The intense heat (flame) thus produced melts and fuses together the edges of the parts to be welded, generally with the addition of a filler metal.

1. Oxy – Acetylene Welding:

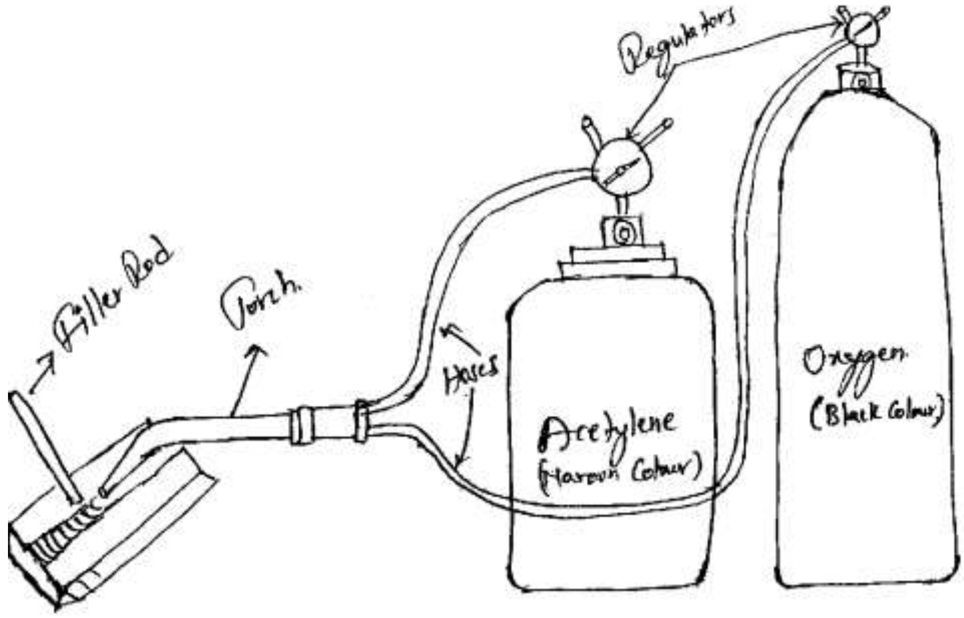
Oxy – acetylene is used for welding almost all metals and alloys. When acetylene is mixed with oxygen in correct proportions in the welding torch and ignited, the flame resulting at the tip of the torch is sufficiently hot to melt and join the parent metal. The flame reaches a temperature of about 3000°C. A filler metal rod is generally added to the molten metal pool to built up the seam slightly for greater strength.

Oxygen is produced by either electrolysis or liquification of air. Electrolysis separates water into hydrogen and oxygen by passing an electric current through it. Most commercial oxygen is made by liquefying air and separating the oxygen from the nitrogen. It is stored in the steel cylinders. Acetylene gas (C_2H_2) is obtained from the chemical reaction of water and calcium carbide.

CaC_2	+	$2H_2O$	-------->	C_2H_2	+	$Ca(OH)_2$
Calcium Carbide		Water		Acetylene		Hydrated Lime

The reaction provides acetylene gas and hydrated lime as sludge. A special hopper of dropping the calcium carbide into a tank of water at controlled rate is referred as acetylene generator. Acetylene cylinders are also readily available.

Equipment for Oxy – Acetylene Welding:



Equipment for Oxy- Acetylene Welding.

Oxy – acetylene welding equipment consists of the following:

(i) Oxygen Cylinder: Oxygen is filled in the cylinder at a pressure of 150 kg/cm2. This cylinder is made of steel and it is in black colour.

(ii) Acetylene Cylinder: Acetylene is dissolved in acetone in a cylinder containing porous calcium silicate filler. These cylinders are usually filled to a pressure of 16 kg/cm2. The cylinder is made of steel and it is in maroon colour.

(iii) Welding Torch: It is used to mix the gases in the right proportions to control the volume of gases burned at the welding tip and to direct the flow. It has a handle to carry it and two inlet connections for gases at one end. Each inlet has a valve to control the volume of oxygen or other gases. The two gases mix up in a mixer and flame is produced by igniting the mixture at the tip of the torch.

(iv) **Pressure Regulator:** It is located on the top of the gas cylinder. Its function is to reduce the pressure from the cylinder and to maintain it at constant value. The pressure regulator located on the oxygen cylinder is called oxygen pressure regulator and the other one located on the top of the acetylene cylinder is called the acetylene pressure regulator.

(v) **Hose and Hose Fittings:** The hose is a rubber tube which permits the flow of gas. Two hoses to carry oxygen and acetylene separately are required. They connect the regulator mounted on cylinders to the torch. Generally, green colour is adopted for oxygen hose and red colour for acetylene. The hose should be strong, durable, flexible and light in weight.

(vi) **Goggles:** Goggles fitted with coloured lenses should be provided to protect the eyes from harmful heat and ultraviolet and infrared rays.

(vii) **Gloves:** These are used to protect hands from heat and the metal splashes during welding.

(viii) **Spark Lighter:** It is used to provide a convenient and instant means for lighting the welding torch.

(ix) **Wire Brush:** Its function is to clean the surfaces of joints before and after welding.

Other Equipments:

Welding Rods: These are used for providing extra metal to the weld. These are also known as filler rods. The filler rod should have the same composition and properties as that of parent metal. The filler rods are available in 1, 1.25, 1.6, 2, 2.25, 3, 4.5, 6, 8 and 10 mm diameter. The selection of filler rod depends on the welding technique and thickness of the base metal. Steel rods are generally employed when welding ferrous metals. They have a higher carbon content and more manganese and silicon than the base metal. The last two components act as deoxidizing agents and prevent the inclusions of oxide in the weld. Rods containing chromium and vanadium are used for welding alloy steels.

Flux: When the metal to be welded is heated by oxy – acetylene flame, the oxygen of the atmosphere combines with the heated metal and forms metal oxides. These metal oxides have higher melting point than the parent metal. Therefore it is essential that these oxides are removed otherwise slag inclusions will result in poor quality of weld. These oxides can be removed from the weld location by the use of certain fluxes which react chemically with the oxides of most metals and from fusible slag and floats at the top of the molten puddle and do not interfere with the deposition of filler metal. Besides it also protects the molten puddle from atmospheric oxygen. Fluxes are available in several forms such as dry powder, paste or in the form of coating on the welding rod. For ferrous metal, borax, sodium carbonate and sodium bicarbonate are used as suitable fluxes. For copper and copper alloys, mixture of sodium and potassium borates, carbonates, chlorides and boric acid are suitable.

Types of Flames:

The correct adjustment of the flame is important for the production of satisfactory welds. The flame must be of proper size, shape and condition in order to operate at maximum efficiency. The three types of oxy – acetylene flames, which are used in engineering works, are as follows;

(a) Neutral flame.
(b) Reducing or carburising flame.
(c) Oxidising flame.

(a) Neutral Flame

(b) Reducing Flame

(c) Oxidising Flame

(a) Neutral Flame: A neutral flame is produced when approximately equal volumes of oxygen and acetylene are supplied to the torch. The temperature of the neutral flame is in order of about 3260°C.

The neutral flame consists of sharp brilliant inner cone extending a short distance from the tip of the torch and an outer cone or envelop. The first one develops heat and second protects the molten metal from oxidation, because the oxygen in the surrounding atmosphere is consumed by gases from flame.

The neutral flame is commonly used for welding most of the metals such as mild steel, stainless steel, cast iron, copper, aluminium etc…

(b) Reducing or Carburising Flame: If the volume of oxygen supplied to the neutral flame is reduced, the resulting flame will be reducing flame. The temperature of the reducing flame is of order of 3038°C.

This flame has three zones (i) Inner core (ii) An intermediate of whitish colour (iii) The bluish outer cone. The outer flame envelop is longer than the other two flames. Being rich in carbon, this flame is suitable for welding steel. It is also used for surface hardening.

(c) Oxidising Flame: If the volume of oxygen to the neutral flame is increased, the result will be oxidising flame. The temperature of the oxidising flame is of the order of 13000°C. It is hotter than neutral flame.

The oxidising flame consists of one smaller core which is more pointed than the neutral flame. The outer envelop is shorter. Oxidising flame is used in welding brass, copper base metals, zinc base metals and few ferrous metals such as manganese, steels and cast irons.

Advantages of Oxy – Acetylene Welding:

1. The equipment is comparatively in expensive.
2. Low maintanenance cost.
3. The oxy – acetylene flame is generally more easily controlled and not as piercing as metallic are welding. Therefore, it is used extensively for sheet metal fabrication and repair works.
4. The equipment is versatile. Besides gas welding, the equipment is used for preheating, brazing, metal cutting etc…
5. With proper technique, practically all metal can be welded.
6. Since the source of heat and filler metal are separate, the welder has controlled over the filler material deposition rates.

Disadvantages of Oxy – Acetylene Welding:

1. It takes considerable longer for the metal to heat up than in arc welding.
2. Prolonged heating of the joint in gas welding results in larger heat affected area. This often results in increased growth, more distortion.
3. These are safety problems involved in handling and storing of gases.
4. Flame temperature is less than the temperature of the arc.
5. Heavy sections cannot be joined economically.
6. Flux shielding in gas welding is not so effective as an inert gas shielding in TIG or MIG welding.

Applications of Gas Welding:

1. For joining thin materials.
2. For joining most ferrous and non – ferrous metals.
3. In automatic and aircraft industries and sheet metal fabrications.

2. Oxy – Hydrogen Welding:

Oxy – Hydrogen welding is used for aluminium, magnesium, lead etc. In this process hydrogen is used in place of acetylene and the flame temperature is very low 2000°C. An advantage of this process is that no oxides are formed on the surface of the weld.

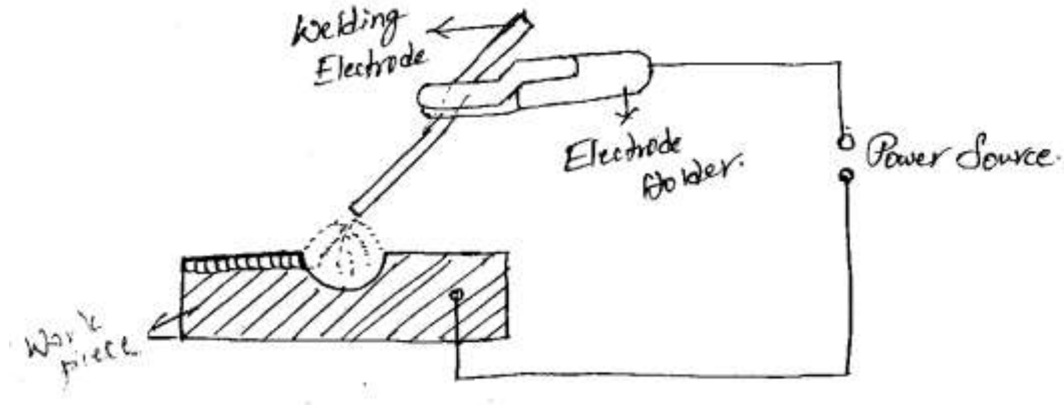
Arc Welding:

In arc welding process, the welding temperature is produced by an electric arc, established between an electrode and the metal being welded. The temperature of the arc is 7000°C. The arc welding set up is shown in below figure.

Arc Welding Equipments:

The equipments required for arc welding consists of:

(a) Arc welding Power Sources
(b) Electrode
(c) Electrode Holder
(d) Cables, Cable connectors
(e) Earthing Clamps
(f) Chipping Hammer
(g) Helmet
(h) Safety Goggles
(i) Apron
(j) Hand Gloves



Arc Welding Setup

(a) Arc Welding Power Source: The power source is required to maintain the arc between the electrode and base metal is available in (i) DC generator (ii) AC transformer with DC rectifier (iii) AC transformer.

(i) DC Generator: DC Generator is run either by an electric motor or diesel engine. These generator supplies voltage in the range of 15 to 50 volts and output current 200 to 600 Amps. These produce DC in either straight or reverse polarity. The heat generated is split into two parts in the ratio of 66 percent at positive pole and 33 percent at negative pole. For welding thin materials, the work is made negative and the electrode positive. This is called reverse polarity. For welding heavy sections the electrode is made negative and the work to be positive, this is called straight polarity. It can be used for welding ferrous and non – ferrous metals. The disadvantage of the generator is the high investment and maintenance cost. Its operation is noisy.

(ii) AC Transformer: AC Transformer changes high voltage, low amperage to low voltage, high amperage. The main advantage of transformer over generator is low cost and ease of operation. Since there are no moving parts in the equipment, the operation is noiseless. The disadvantage of the transformer is that the polarity cannot be changed.

(b) Electrodes for Arc Welding: Electrodes for arc welding may be broadly classified as:

1. Non – consumable electrodes
2. Consumable electrodes

Non – Consumable electrodes are usually made of carbon, graphite or tungsten. These electrodes do not get consumed during the arc welding. These are used in carbon arc welding like TIG welding, atomic hydrogen welding.

Consumable electrodes get consumed during the welding. These are made of various metals depending upon the purpose and chemical composition of patent metals being welded. These electrodes are further classified into, (1) Bare Electrodes (2) coated electrodes.

Bare electrodes are used in submerged arc welding and metal inert gas welding (MIG) welding.

Coated electrodes are again subdivided into (1) Light coated electrodes (2) Heavy coated electrodes.

Light coated electrodes are used for welding non–essential jobs. The primary purpose of light coated is to increase are stability. These produce poor mechanical properties welds due to the lack of protection of the weld.

Heavy Coated electrodes are used to produce high quality welds.

Functions of Coated Electrode:

The coating on electrodes performs the following function:

1. Protects the weld from atmospheric oxygen and nitrogen by producing a shield of gas around the arc and weld pool.
2. Stabilize the arc.
3. Provide the slag so as to protect the weld from rapid cooling.
4. Remove oxides and impurities.
5. Add alloying elements to the weld metal.
6. Increase deposition efficiency.

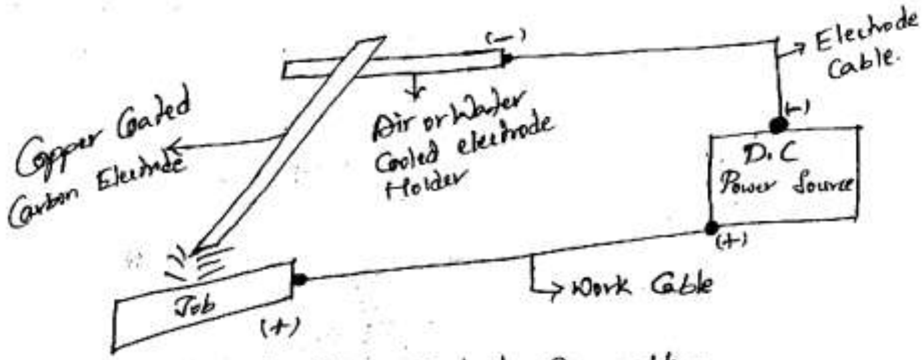
Types of Arc Welding:

(a) Carbon arc welding
(b) Metal arc welding
(c) Submerged arc welding
(d) Inert gas welding
 (i) TIG welding (ii) MIG Welding
(e) Plasma arc welding
(f) Electro Slag welding

(a) Carbon Arc Welding:

In carbon arc welding process the arc is obtained between the carbon electrode and the work piece or between two carbon electrodes. This welding is suitably used in welding of steel sheets, copper alloys and brass etc…

In this, coalescence is produced by heating with an electric arc between a carbon electrode and the work. Shielding is generally not used. Pressure is not used, and filler metal may or may not be used. The electric are can also be struck by the "twin arc method" that is between two carbon electrodes. Filler metal, when used is fed into the arc and allows a fairly high rate of weld metal deposition. Sometimes a filler rod is placed into the joint groove, and the carbon arc is passed slowly along the joint until fusion is completed.



Single Carbon Electrode Arc welding.

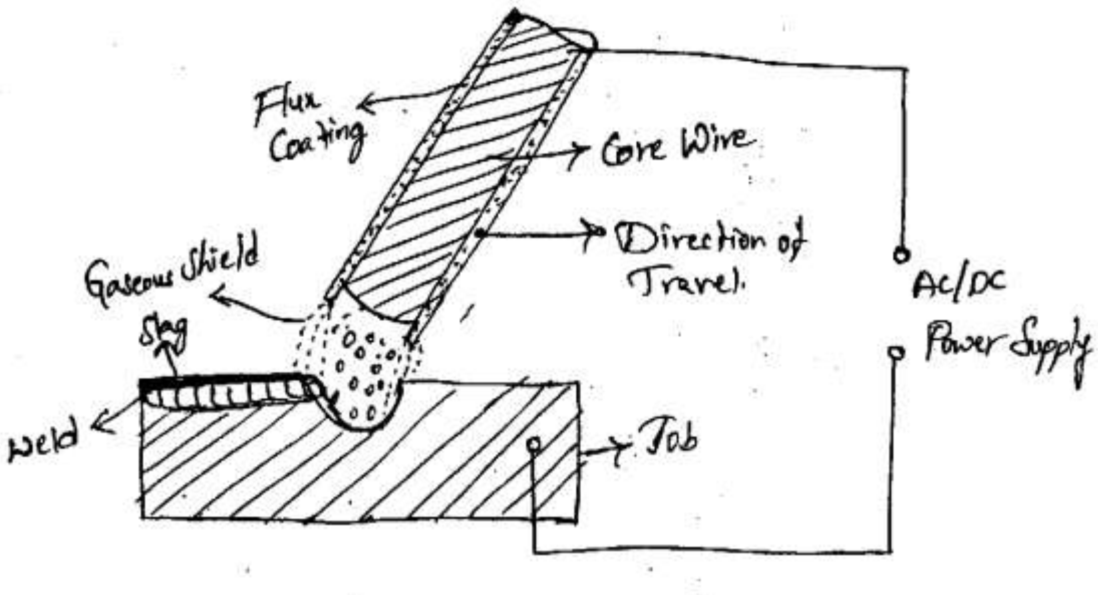
The weld metal is not shielded from contamination of oxygen and nitrogen in the atmosphere. More ever, very little if any carbon is picked up by the weld from the carbon electrode. Thus this process is generally limited to those materials which are not sufficiently contaminated by these elements, that are copper alloys, brass, bronze, aluminium alloys etc… It will be better if the filler metal incorporates deoxidizer.

(b) Metal Arc Welding:

This is also called Shield Metal Arc Welding (SMAW). Heat required for the welding is obtained from the arc struck between the coated electrode and the work piece. The material droplets are transformed from the electrode to the work piece through the arc and deposited along the joint to be welded. The coating produces a gaseous shield and slag to protect from atmosphere.

During the process of welding, the electrode is given three movements. The electrode is continuously fed downward along its axis to maintain the arc length. It is progressively fed along the weld and thirdly the electrode tip is given an oscillating movement across the weld. The side ways oscillating movement of the electrode tip is given to:

(i) Obtain and maintain proper bead width.
(ii) Float out slag.
(iii) Secure good penetration at the edges of the weld.
(iv) Allow gases to escape and there by avoid porosities.



Metal Arc Welding.

Advantages:

1. It is the simplest of all the arc welding processes.
2. The equipment is portable and less cost.
3. Wide range of metals and their alloys can be welded.

Disadvantage:

1. Mechanization is difficult due to limited length of the electrode.

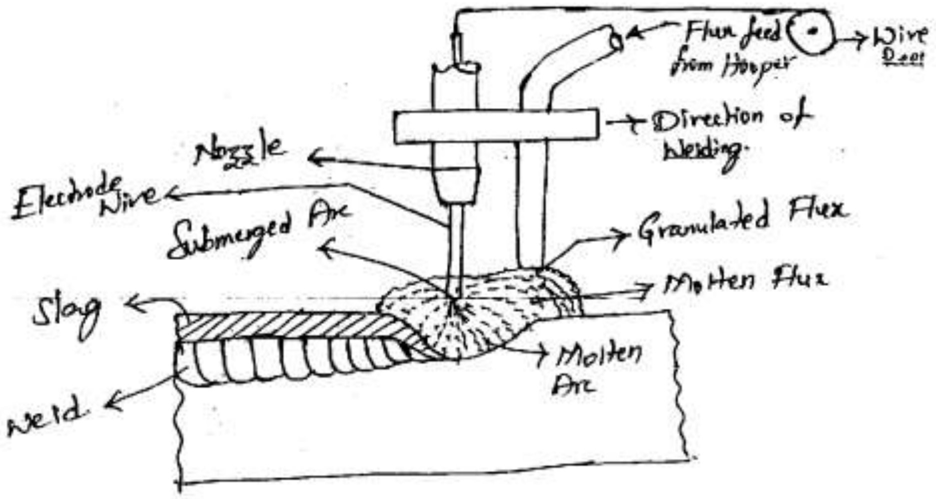
Applications:

1. All commonly used metals and their alloys can be welded.
2. This process finds application on ship building, aircraft industries, automobile industries etc…

(c) Submerged Arc Welding:

This process is so named because of metal arc is shielded by a blanket of flux as shown in figure. In this process instead of flux covered electrode, granular flux and a bare electrode is used. Flux is deposited continuously in front of the electrode and the flame feeder and the electrode feeder together move as the welding proceeds. The flux is sufficient depth to submerge completely the arc column so that there is no smoke or splatter and the weld is shielded from the effect of all atmospheric gases. As a result of this unique protection, the welds are exceptionally smooth.

The arc is started either by striking the electrode beneath the flux on the work or by placing the steel wool between the electrode and the work piece before switching on the welding current. The intense heat of the arc immediately produces a pool of molten metal in the joint and at the same time the flux adjacent to the arc column melts and floats on top of the molten metal. This forms a blanket that eliminates spatter losses and protects the welded joint from oxidation. The current density is 300 to 400 amps which is 5 to 6 times than that of metal arc welding. Submerged arc welding is done manually or automatic and semi-automatic. The manual and the automatic submerged arc welding process are most suited to the flat welding position, or slightly vertical, down hill welding position. Backing strip of steel, copper or some refractory material is used under the joint to avoid loosing some of the molten metal.



Submerged Arc Welding.

This process is used to weld low alloy, high tensile steels as well as mild steel, low carbon steels.

Advantages:

1. Deep penetration is obtained due to the high current, density which is 5 to 6 times than that of metal arc welding.
2. Welding is fast due to high melting rate of electrodes.
3. Minimum distortion due to high speed.
4. Quality of the weld is excellent and uniform.

Applications:

The submerged arc welding process has many industrial applications. It is used for fabricating pipe, boiler vessels, structural shapes and practically any job where straight line welding is required.

(d) Inert gas welding:

In this coalescence is produced by heating with an electric arc between a suitable electrode and the work. Shielding is obtained form an inert gas such as carbon dioxide, helium and argon. Pressure is not used, and the filler metal may or may not be used. Inert gas welding is done either with nonconsumable electrode or with consumable metal electrode.

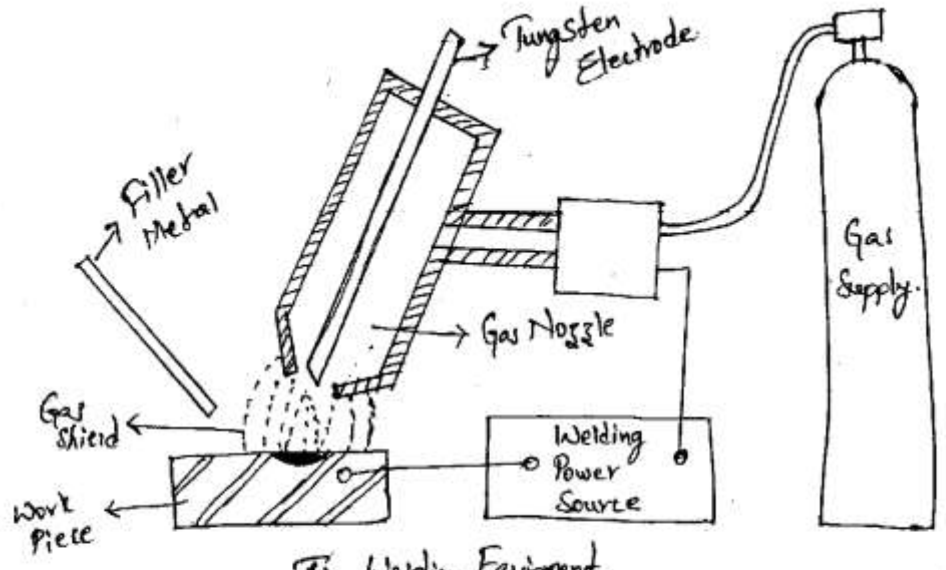
In conventional arc welding, the fluxes are used to shield the atmosphere around the molten metal. In inert gas welding, inert gases such as argon, helium, carbon dioxide are used for surrounding the electric arc and thus keeping atmospheric air and other contaminations away from the molten metal pool.

Two methods are employed.

(i) Tungsten-inert Gas (TIG) Welding
(ii) Metal-inert Gas (MIG) Welding

(i) Tungsten – inert Gas Welding:

A tungsten inert gas welding equipment is shown in below figure. This process is also known as gas tungsten arc welding (GTAW). It uses a non-consumable tungsten electrode mounted at the centre of the torch. The inert gas is supplied to the welding zone through the angular path surrounding the tungsten electrode. Welding operation is done by striking the arc between the work piece and tungsten electrode in the atmosphere of inert gas.



Tig Welding Equipment

Advantages:

(i) No flux is required.
(ii) TIG welds are stronger, more ductile and more corrosion resistance than welds made with ordinary shield arc welding.
(iii) Welding is easily done in all the position.

Disadvantages:

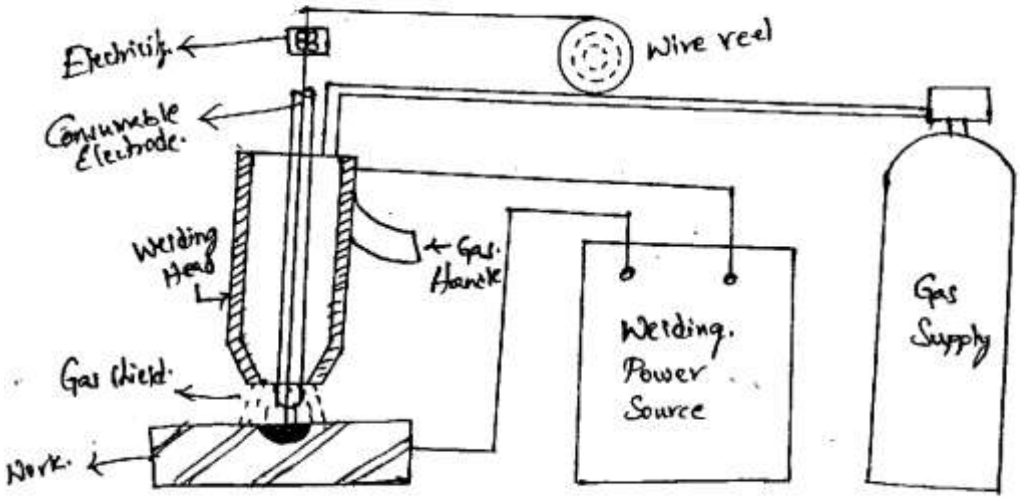
(i) Equipment is costlier.
(ii) Separate filler rod is needed.
(iii) Decrease in welding speed.

Applications:

(i) It is used for fusion welding of aluminium, magnesium alloys, stainless steel, low alloy steel high alloy steel, brass, bronze, silver, molybdenum and a wide range of other metals.
(ii) It can also be used to weld many dissimilar metals.
(iii) The TIG process can be used to braze and to supply the heat source for brazes welding.
(iv) It can also be used as heat source for the hard surfacing of the metals.

(ii) Metal Inert Gas (MIG) Welding:

MIG welding stands for Metal Inert Gas Welding. In this process, the tungsten electrode is replaced with a consumable electrode. The electrode is continuously fed to the arc at the rate at which it is consumed and transferred to the base metal. Arc is shielded by an inert gas, which flows from the holder nozzle through which the electrode also passes. It is similar to submerged arc welding in feeding the bare electrode from a reel. It differs in the fact that the shielding is done by an inert gas and the arc is visible during the welding process.



Mig Welding Set up

Advantages:

(i) No flux is required.
(ii) High quality welds are produced.
(iii) Less operator skill is required.
(iv) High welding speed.
(v) It is suitable for ferrous and non-ferrous metals.

Disadvantages:

(i) Welding equipment is more complex and costly.
(ii) It is difficult to weld in small corners.

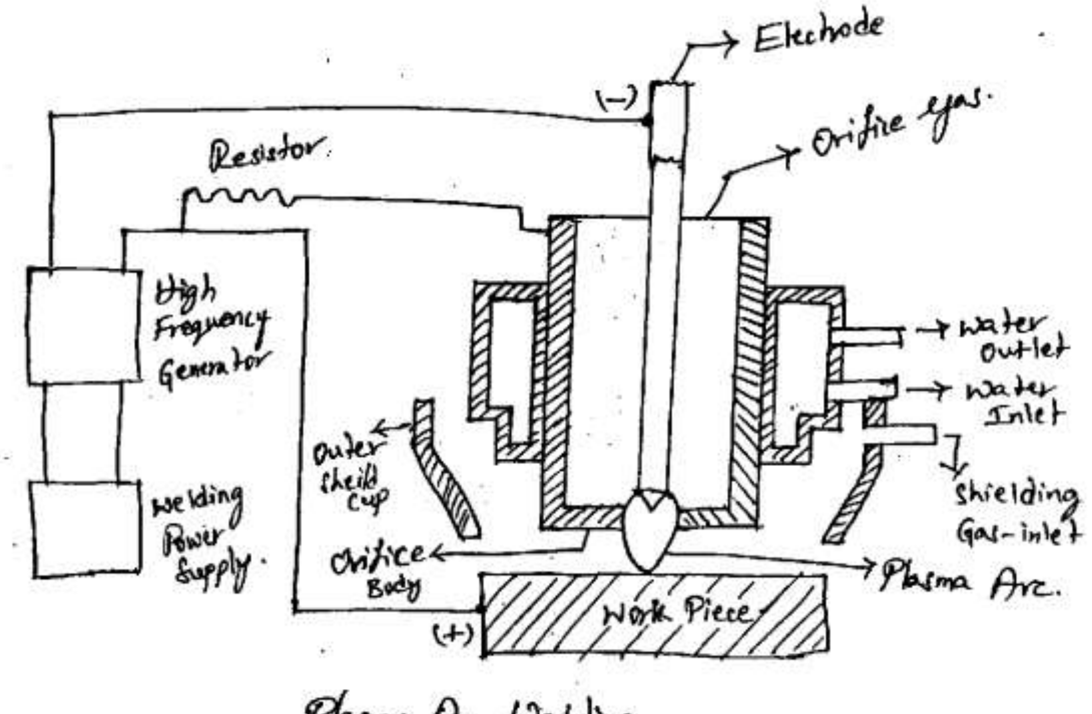
Applications:

(i) It can be done on most of the commercial metals.
(ii) It is used for welding carbon and low alloy steels, stainless steels nickel and its alloys, copper alloys.
(iii) MIG welding is used in aircraft and automobile industries.

(e) Plasma Arc Welding:

The term 'Plasma' refers to a gas which is sufficiently ionized to conduct freely. A conventional welding arc is an example of plasma. A plasma jet is created when the arc is passed through a constructive nozzle. As a result of this construction the plasma jet will take on a narrow, columnar shape with unique properties that make it ideal for welding. Plasma jet welding is an electric arc welding process which employs a high temperature constricted arc or plasma jet to obtain the melting and coalescence of metal. Shielding is obtained from the hot, ionized gas issuing from the nozzle, which may be supplemented by an auxiliary source of shielding gas. Pressure is not applied and filler may or may not be supplied.

The basic circuitry of a plasma arc welding torch is shown in below figure. The plasma torch is constructed with an electrode centrally with in a metal cup that guides an inert streaming gas past the electrode. The discharge end of the cup is smaller in diameter than the upper diameter so that a discharge nozzle is created. In addition, the inner wall of the nozzle is lined with a ceramic material. The torch ahs passages for supplying gas and water i.e., air and water to cool in.



Plasma Arc Welding.

There are two arrangements of plasma arc welding:

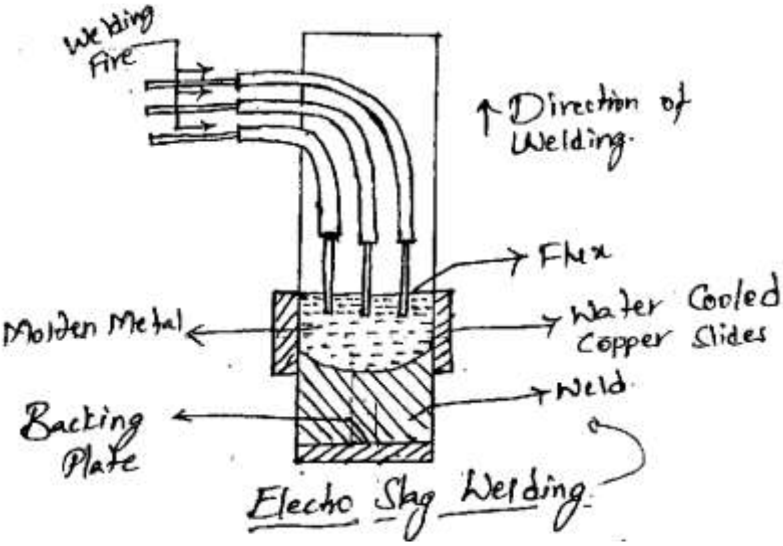
(a) Transferred Plasma arc.
(b) Non – transferred Plasma arc.

In the transferred plasma arc, the arc is produced between the electrode (-ive) and the work (+ ive). In other words the arc is transformed from electrode to the work piece. This possesses high energy density. For this reason it is used to cut and melt the metals.

In the non-transferred arc, the arc is produced between the electrode (- ive) and the nozzle (+ ive). Plasma arc comes out of the nozzle as a flame. This arc is independent of the work piece and the work does not form a part of electric circuit. This arc is used for only welding.

(f) Electro Slag Welding:

In this process, electrode wire is fed into a molten slag pool. An arc is drawn initially, but is then snuffed out by the slag, and the heat of fusion is provided by resistance heating in the slag.



The pieces to be welded are positioned vertically with necessary gap between them. Two copper shoes (water cooled) sides on either side of the gap form a well in which flux is deposited. An electric arc is stuck between the electrode and the joint bottom with the help of a piece of steel wool. The arc melts the electrode and flux and forms the molten slag. When enough slag accumulate, the arc action stops and further requirement heat is provided by the resistance offered by the slag to the current flowing through it. The molten metal temperature is 2000°C. This heat is sufficient to fuse the edges of the work pieces and the welding electrode. The heated metal collects in the pool beneath the slag slowly solidifies there by forming the weld bead joining the two work pieces.

Advantages:

(i) Thicker plated can be welded in a single pass and economically.
(ii) High welding speed.
(iii) Minimum joint preparation.
(iv) Little distortion.
(v) The weld metal is totally out of contact with atmosphere and hence the best quality of weld.

Applications:

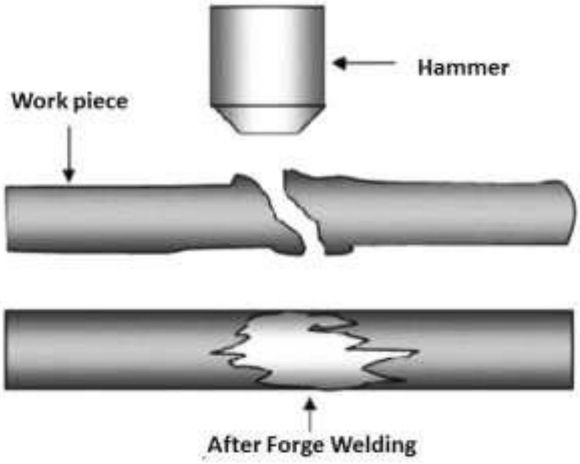
It is used particularly for welding thickness of 30 mm over plates and structures for turbine shafts, boiler parts and heavy presses.

Forge Welding:

Forge Welding is defines as "A solid state welding process where in coalescence is produced by heating and by applying pressure or blows sufficient to cause permanent deformation at the interface".

This is the oldest industrial welding process. The parts to be welded are heated in a forge or some other furnace to within the hot-working temperature range and then forged together by hand or power hammering or pressing. During forging, oxides slag and other contaminants are squeezed out, ensuring inter atomic bonding.

The work pieces commonly forge welded and are of wrought iron and steel. The commonly used forge welding processes are : (i) Hammer welding (ii) Die welding, and (iii) Roll welding.



Resistance Welding:

Resistance welding is "a group of welding processes where in coalescence is produced by the heat obtained from resistance of the work to electric current in a circuit of which the work is a part, and by the application of pressure and without the use of a filler metal".

In this welding, a heavy electric arc current is passed through the metal pieces to be joined, over a limited area, causing them to be locally heated to plastic state and the weld is completed by the application of pressure. In this process two copper electrodes are used. The metal pieces to be welded are pressed between electrodes and current is passed through the electrodes. A transformer in the welding machine reduces the voltage from either 120 or 240 volts to4 to 12 volts and raises the amperage sufficiently to produce a good heat.

The amount of heat (H) generated is given by the following relation:

$$H = KIRT$$

Where, H = The heat generated in the work in joules
I = Electric current in amperes
R = Resistance of the joint in ohms
T = Time of current flow in seconds
K = A constant to account for the heat loss from the welded joint

For good resistance welding the following factors are properly controlled.

(i) **Welding Current:** Enough current is required to bring the work pieces to plastic state for welding. It is properly adjusted on the current control device on the machine.
(ii) **Welding Pressure:** Mechanical pressure is required to hold the work pieces and squeeze the pieces to form the weld during plastic state.
(iii) **Cycle Time:** It is the combination of weld time and hold time. The duration of current flowing through the work piece to raise the temperature is called welding time. After this the current is switched off while the pressure is still acting. The pressure is applied till the weld cools and regains sufficient strength. This period is known a hold time.

The types of resistance welding are:

(a) Spot Welding (b) Seam Welding
(c) Projection Welding (d) Butt Welding

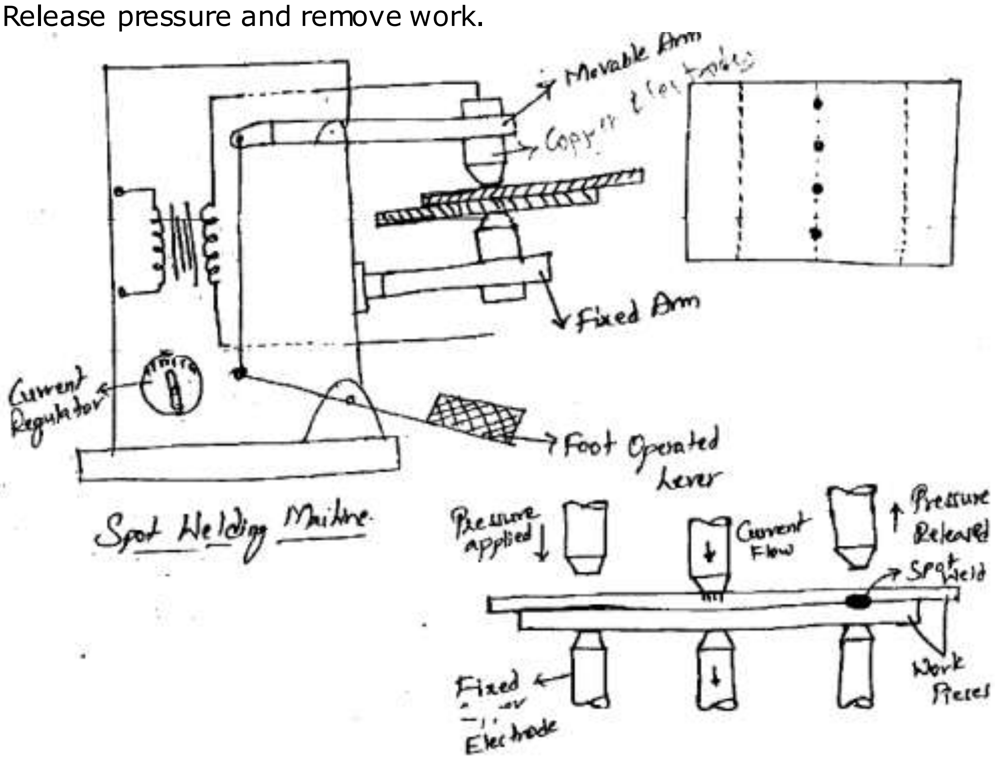
(a) Spot Welding:

This is called as Resistance Spot Welding (RSW). It is the simplest and most commonly used method of overlap welding of strips, sheets or plates of metal at small areas.

In this method, sheets of a metal to be welded are held between copper electrodes (water cooled) by applying pressure through foot pedal lever. A current of low voltage and sufficient amperage is passed between electrodes causing the parts to be brought to welding temperature. The metal under electrodes pressure is squeezed and welded. After this the current is turned off while the pressure is still acting. The pressure is applied till the weld cools and produces a solid bond. Now the pressure is released and the work is removed from the machine.

The welding cycle to produce one spot can be written as:

(i) Position the work pieces and squeeze between the electrodes.
(ii) Apply a low voltage current to the electrode.
(iii) Hold until the proper temperature is attained.
(iv) Release current, continue pressure.
(v) Release pressure and remove work.



Advantages:

(i) No edge preparation is needed
(ii) Low cost
(iii) High speed of welding

Applications:

(i) This technique is used mostly in thin sheet work like making sheet metal boxes, containers such as receptacles.
(ii) Thicker metals up to 12.5 mm have been successfully spot welded.
(iii) It finds application in automobile and aircraft industries.

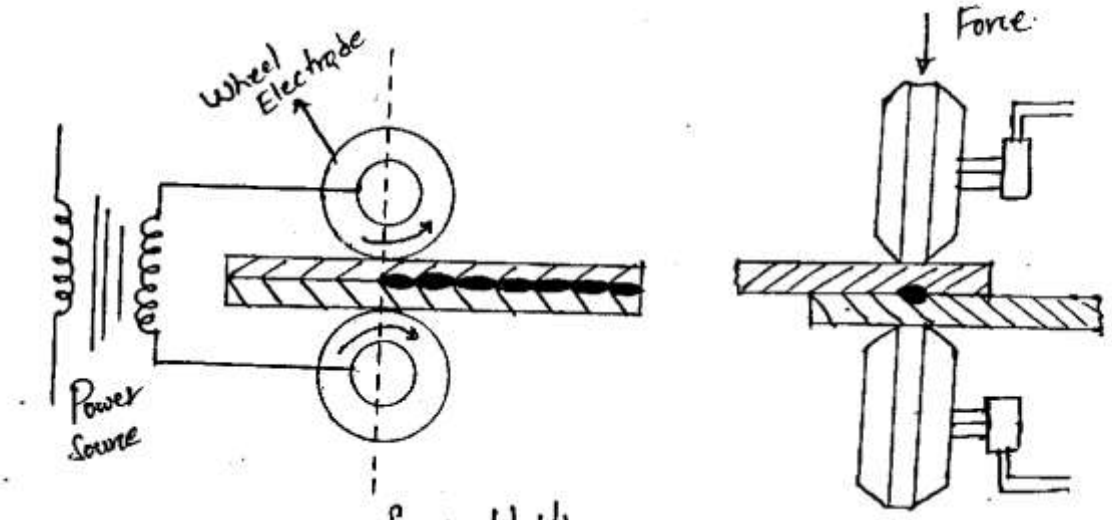
Disadvantages:

The main disadvantage is high cost of equipment, and there are limitations to the types of joints made.

(b) Seam Welding:

Seam welding is similar to spot welding, except that the electrodes in spot welding are replaced by copper rollers or wheels. The work pieces to be welded are passed between the rollers as shown in figure. A current impulse is applied through the rollers to the material in contact with them. The heat generated makes the metal plastic and the pressure from the rollers completes the weld.

To obtain a series of spot welds along a line by the RSW (Resistance Seam Welding) method, an interrupt work movement will be necessary. The same result can be achieved much more conveniently and rapidly in the resistance seam welding where the electrodes are in the form of rotating disc electrodes, with the working being welded moving continuously by the electrodes.



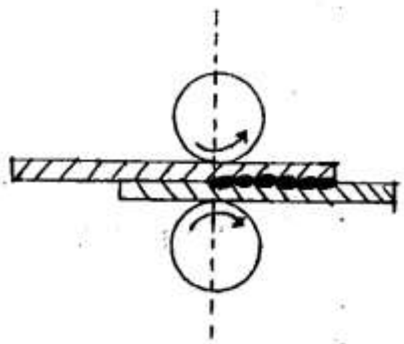
Seam Welding.

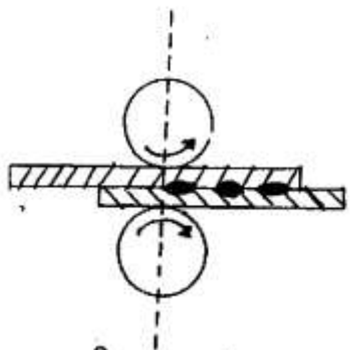
In Seam welding, there are two types of welds are obtained:

(i) Stitch Welding
(ii) Roll Welding

(i) Stitch Welding: Stitch weld is made by the current on the rollers off and on quickly enough, so that continuous fusion zone made of overlapping nugget is obtained.

(ii) Roll Welding: It is obtained by constant and regular timed interruptions of welding current, which causes individual nuggets to be formed.


Stitch Welding.

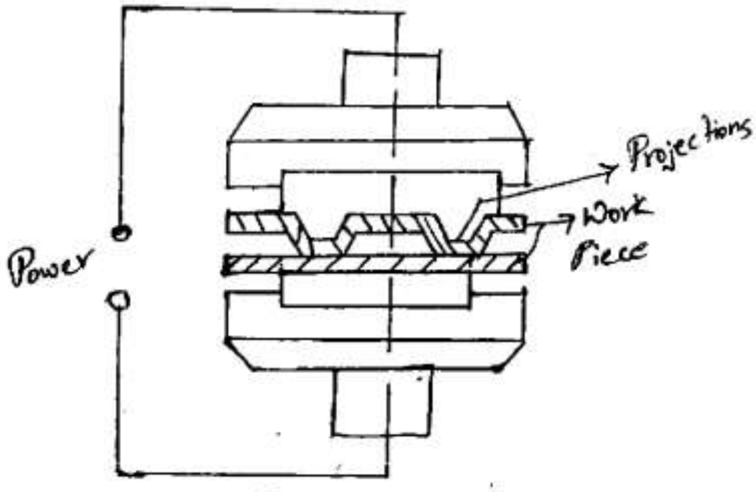

Roll Welding.

Seam welding is used on many types of pressure tight or leak proof tanks for various purposes, exhaust systems, barrels etc…

(c) Projection Welding:

The Resistance Projection Welding process is similar to spot welding except that the current is concentrated at the spots to be welded.

In this welding small projections are raised on one side of the sheet or plate where it is to be welded to another. The projections serve to concentrate the welding heat at these areas and facilitate fusion without the necessity of employing a large current. During the welding process, the heated and softened projections collapse under the pressure of the electrode there by forming the weld. The working principle of projections welding is shown in below figure.



Projection Welding.

Advantages:

(i) This method of welding gives longer electrode life.
(ii) Outer or top surfaces can be produced with no electrode marks.

Disadvantages:

(i) All projections should be seated in one blow.
(ii) A prior operation is necessary to form the projection.

Applications:

A common use of projection welding is attaching small fasteners, nuts, special blots, studs and similar parts to large components.

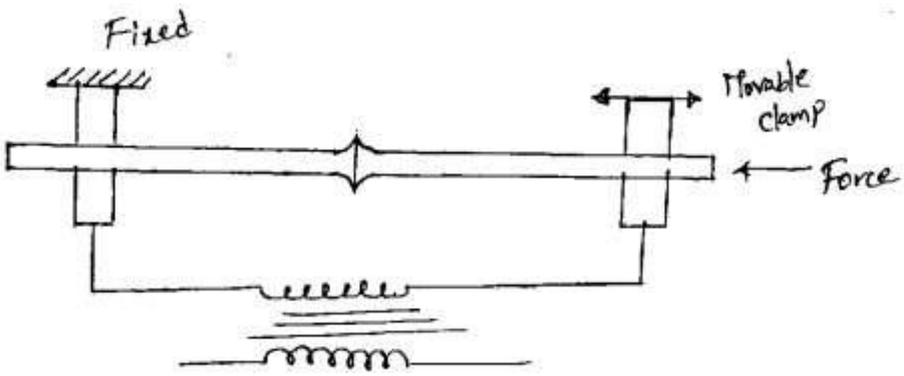
(d) Butt Welding:

Resistance Butt Welding is used to join the pieces end to end. This process is best suited to rods, pipes and many other parts of uniform cross section.

There are two types of Resistance Butt welding:

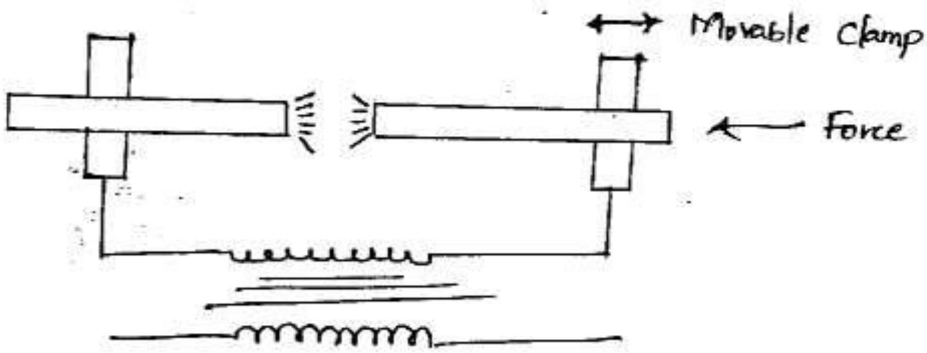
(i) Upset welding
(ii) Flash Welding

(i) Upset Welding: In upset welding, the parts are clamped and brought in solid contact and current is applied so that the heat is generated through the contact area of the parts as illustrated in below figure. At this point, the two parts are pressed together firmly. This action of pressing together is called upsetting. It is used on non-ferrous materials for welding bars, rods, tube formed parts etc…



Upset Butt Welding.

(ii) Flash Welding: Flash welding is similar t upset welding except that the heat is obtained by means of an arc than the simple resistance heating. The two parts are brought together and the power supply is switched on. As the parts moved closer, flashing or arcing raised the temperatures of the parts to a welding temperature. Now power is switched off and the parts are forced together to form a weld.



Flash Butt Welding.

Thermit Welding:

This process is a type of thermo chemical welding process. Thermit welding is "A group of welding processes where in coalescence is produced by heating with superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminium with or with out the application of pressure".

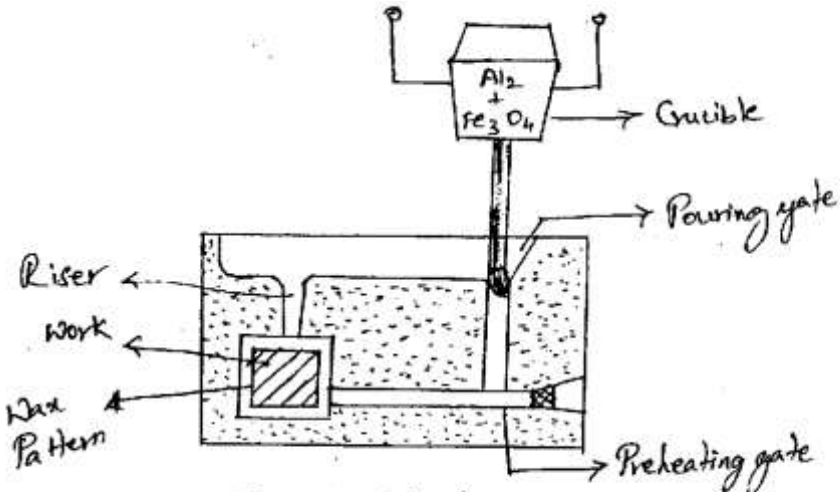
The process is basically a fusion welding process in which welding is effected by pouring super heated steel around the parts to be welded. In this process, neither arc is produced to the parts nor flame is used. In this an exothermic chemical reaction is utilized for developing high temperature.

A mixture of finely divided aluminium and iron oxide called 'Thermit mixture' is kept in a crucible hanging over the mould. The Thermit mixture is ignited using a magnesium ribbon or highly inflammable powder having barium peroxide. The reaction takes place about 30 seconds only and heat is liberated which is twice the temperature of melting point of steel. The following reaction takes place as per equation:

$$8AI + 3F_3O_4 \text{ ------------- > } 4Al_2O_3 + 9Fe + heat$$

The resultant is super heated molten iron. The molten iron is made to flow into the mould and fuse with the parts to be jointed.

The figure shows the method of preparing the mould. The two pieces to be joined are cleaned and a gap is left between them. Then wax is poured on the joint and a wax pattern is formed. Moulding sand is rammed around the wax pattern and pouring, heating and risering gates are cut. A gas flame is used melt the wax pattern and at the same time it preheats the parts to be welded. Then the preheating gate is plugged with sand. When the ends of the pieces to be welded reach the welding heat, they are forced together by means of clamps to make a pressure butt weld. The mould is then removed and the Thermit iron and slag are knocked off from around the weld.



Thermit Welding.

Advantages:

(i) The welds are sound and free internal residual stresses.
(ii) Broken parts can be welded on the site itself.
(iii) The heat necessary for welding is obtained from a chemical reaction and thus no costly power supply is required.

Limitations:

Thermit welding is applicable only to ferrous metal parts of heavy sections.

Applications:

It is applicable in the repair of heavy parts such as rail track, spokes of driving wheels, broken motor castings, connecting rod etc.

Cutting of Metals:

The welding equipments are not only used for welding that is joining the work pieces but some of the equipments are also used for cutting of the metals.

Oxy – Acetylene Cutting:

It is a chemical process in the sense that the metal, at the portion where it is to be cut is actually made to oxidize under the action of flame with the following reaction.

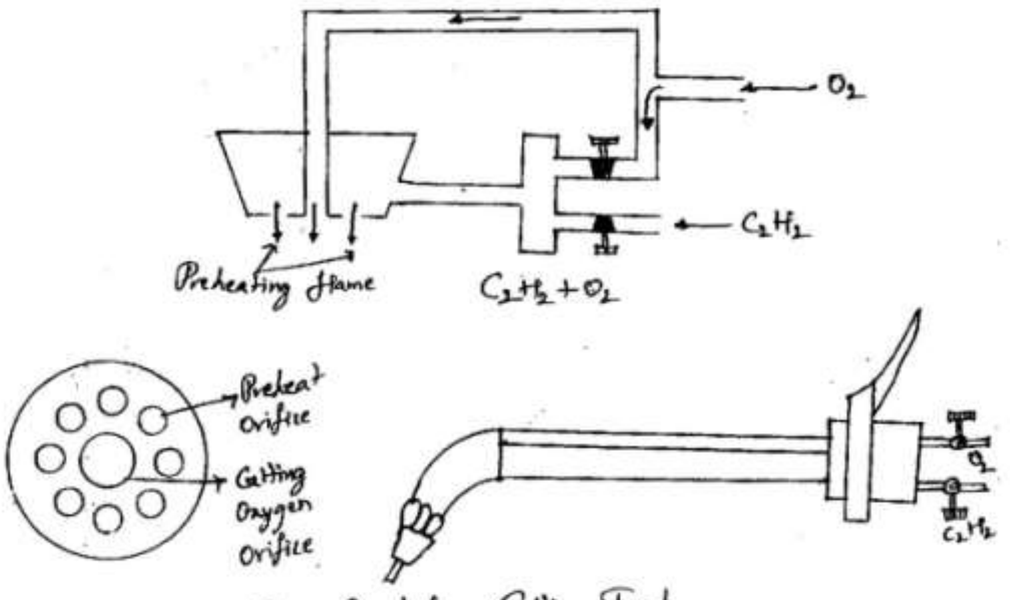
3Fe	+	$2O_2$	---------->	Fe_3O_4	+	26,691 cal
Iron		Oxygen		Black Iron		Oxide Heat

All ferrous metals can be cut by means of oxy-acetylene flame cutting. The oxy-acetylene flame cutting process makes use of cutting torch. The torch mixes the acetylene and oxygen in the correct proportions to produce preheating flame and also the torch supplies a uniformly, concentrated stream of high purity oxygen to the reaction zone. The tip has a central hole for pure oxygen jet with surrounding holes for preheating flames as shown in below figure.

To produce a cut, the steel is heated to ignition temperature (900°C) i.e., reddish yellow colour by preheating flame, keeping the torch 3 mm above the surface of material to be cut. A jet of pure oxygen is directed at this heated area. This forms the iron oxide there and the same melted immediately (burning the steel in its path). It is then blown off by the oxygen jet, thus providing a narrow slit along the cutting line.

This method is suited for cutting of ferrous metals and its alloys.

Oxygen cutting can be accomplished manually or by machine (automatic).



Oxy-Acetylene Cutting Torch.

Oxygen cutting machines are further divided two classes:

1. Portable machine
2. Stationary machine

On a portable machine, the carriage supports the torch. It is usually run by an electric motor on a straight track. The speed of the motor is adjustable to the size of the metal being cut.

The stationary type of cutting machines is designed on two different mechanical principles for cutting torch. One is the pantograph design and the other uses a cross carriage mechanism.

Plasma Arc Cutting:

As we know, plasma is the high temperature ionized gas. The plasma arc cutting is done with a high speed jet of high temperature plasma. The plasma jet heats up the work piece causing a quick melting. Plasma arc cutting can be used on all those materials which conduct electricity, including those which are resistant to oxy-fuel cutting. The process is extensively used for profile cutting sheets upto 40 mm thick by using programmable logic controllers (PLC) or CNC.

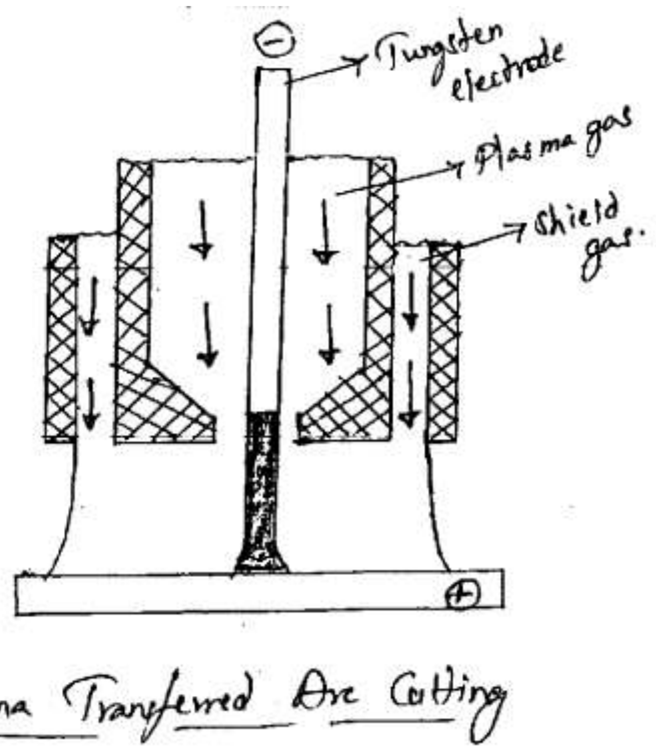
Plasma is generated by subjecting the flowing gas to the electron bombardment of an arc. For this the arc is set up between the electrode and anodic nozzle, the gas is forced through the arc. Gases used or plasma arc O_2, N_2 and H_2. The method produces higher temperatures of about 9500°C.

The process has got the following advantages:

1. The process is fast, that is high cutting speeds.
2. Good surface finish.
3. Good reproducibility of parts.
4. Higher productivity than that of oxy-fuel methods.
5. The process is very economical.

Due to the above advantages, it is the preferred way to produce large quantities of cut parts.

Cutting is done under water to avoid distortion of sheets due to high temperatures generated. Water also helps in accurate cutting, cooling the metal and protecting eyes from plasma arc.



Soldering:

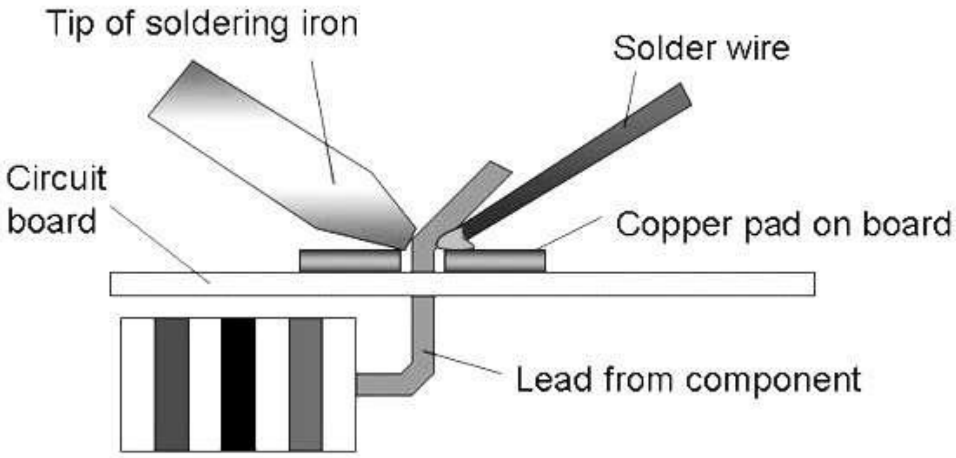
It is a method of joining two pieces of metal by means of a fusible alloy called solder, applied in the molten stage. The melting point of the filler metal is below 420°C. The solder is usually an alloy of Lead and Tin, Lead and Silver. A suitable flux is used in soldering to prevent oxidation of the joint. Fluxes are available in the form of powder, past or liquid.

A good soldering process involves: (i) Pre Cleaning (ii) Fluxing (iii) Heating

(i) **Pre-Cleaning:** Cleaning is done to provide chemically clean surface to obtain proper bond and may be done by means of acid pickling, solvent cleaning etc…

(ii) **Fluxing:** Fluxing is done to remove the oxides from joint surface and to prevent the filler metal from oxidizing. Fluxes are in form of powder, paste or liquid.

(iii) **Heating:** The most common source of heating is the electrical resistance heating with soldering iron. Other methods of soldering are disoldering, wave soldering, oven soldering, induction soldering and infra red soldering.



Soldering is done in the following ways:

(i) **Hand Soldering:** The soldering iron is heated by keeping in a furnace or by means of electrically. The joint is heated by soldering iron and solder is applied which melts and flows the joint by capillary action.

(ii) **Dip Soldering:** In dip soldering, the parts to be soldered are first cleaned and dipped in flux bath and finally dipped in the molten solder bath and lifted after the soldering is completed.

(iii) **Wave Soldering:** In this method, parts are not dipped into the solder tank, but a wave is generated in the tank so that the solder comes up and makes necessary joint. This is used in electronic printed circuit board, PCB.

Brazing:

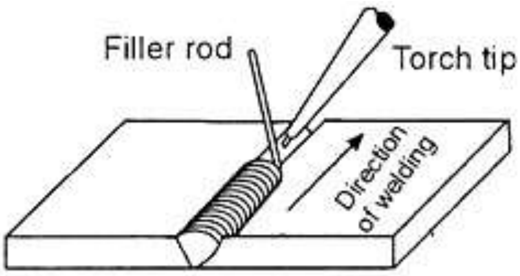
It is a process of joining two pieces of metals in which a non-ferrous filler metal or alloy is introduced between the pieces to be joined. The melting point of the filler metal is above 420°C but lower than the melting temperature of parent metal. The filler metal is distributed between surfaces by capillary action. The copper base alloys and silver base alloys are commonly used as filler metal in brazing. A suitable flux such as borax is used.

Steps in Brazing:

(i) The surfaces to be joined are cleaned and subsequently rinsed and dried and fitted closely together.

(ii) A flux is applied to all surfaces where the filler metal is to flow.

(iii) After that, the joint is heated to the proper brazing temperature. Solid filler metal may be replaced on the metal pieces and thus melted as the metal pieces are heated, or it may be applied to the metal pieces after the brazing temperature is reached. Only a small amount of filler metals needed to fill the joint completely.



Fluxes: Fluxes are used to prevent oxidation of the base metal and the filler metal during brazing, form a fusible slag of any oxides which may be present or formed, and promote the free flowing of the filler metal by capillary attraction.

Common fluxes are: compositions of borates, fluorides, chlorides, borax and boric acid in various proportions according to specific requirements. Fluxes are used in form of powder, paste or slurry. Borax is used as fused borax, because water in it will cause bubbling during heating.

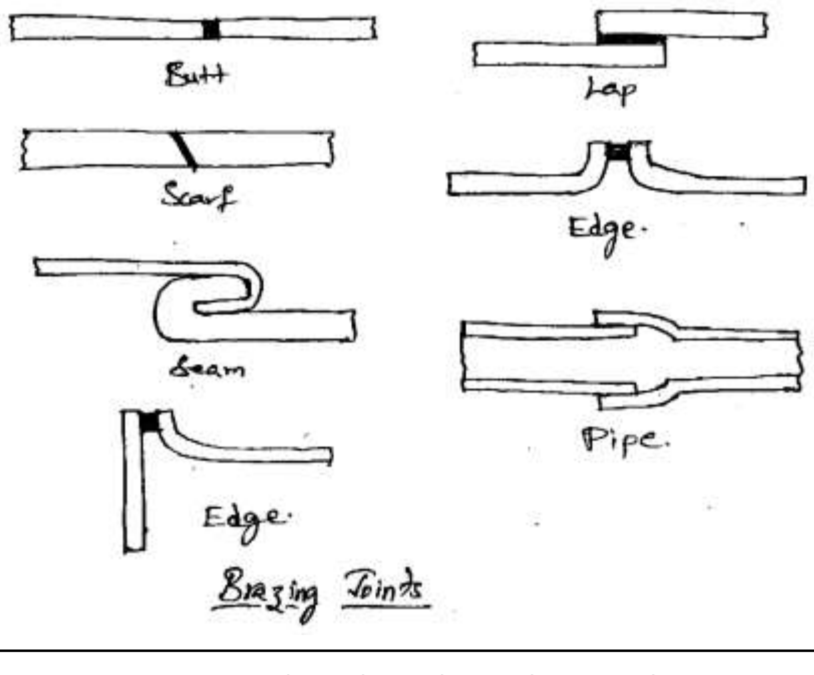
Filler Materials: The filler metal or braze metal must:

1. Wet the surfaces of the base metals at the joint.
2. Have high fluidity to penetrate crevices. For capillary attraction to exist, the clearance between the parts being joined must be quite small, other wise the filler metal would run out of the joint. A wider clearance in a joint leads to its reduced strength.
3. Preferably have a narrow melting range.
4. Not lead to galvanic corrosion during service.

The filler metal is applied in the form of wire, strip, performs, powder or paste to the joint area as noted above in step (iii) under 'steps in brazing'. Alternatively the filler metals pre applied to the surface of one of the contacting parts as a coating or cladding, often by rolling, electrolyte deposition or hot dipping.

Brazing Joints:

The following are the different type of Brazing joints which are regularly used at different applications.



Brazing Methods:

The selection of brazing method is based on the size and shape of the components to be joined, the base metal and the production rate.

(a) Torch Brazing: Torch brazing is the most versatile method. It is similar to oxy-acetylene welding. In this process, reducing flame is used to heat the joint area. A flux is applied and as soon as it melts, the filler metal is hand fed to the joint area. When the filler metal melts, it flows into the clearance between the base metal components by capillary action. This method finds applications in fabrication industry and repair work.

(b) Furnace Brazing: In this method the atmosphere of the furnace is controlled to prevent oxidation by hydrogen, dissociated ammonia, nitrogen or any gas, thus allowing the molten brazing metal to flow smoothly and uniformly around the joint.

(c) Induction Brazing: In these metals, the metals to be welded are surrounded by metallic coils through which high frequency current is passed. This induces eddy current which produces localized heating. The parts to be brazed are pre-fluxed and the brazing is placed in the joint before switching on the current.

(d) Dip Brazing: In dip brazing, the parts to be brazed are dipped into a bath of molten filler metal covered by a layer of molten flux. Surface not required to be coated with the brazing alloy must be protected by molasses or by lamp black. This process is used for small parts.

(e) Salt Bath Brazing: The source of heating in salt bath brazing is a molten bath of fluoride and chloride salts. This salt bath removes thin oxide films from the metals to be joined. The filler metal replaced in the joint area and is also sometimes cladded before dipped in the salt bath.

(f) Resistance Brazing: It is similar to spot welding. Electrical resistance is used for joining parts. The parts to be joined are placed between the electrodes of the welding machine with the filler metal and flux preloaded at the joint area. Current is then applied until the filler metal melts and flows around the joint.

Advantages:

(i) It gives a stronger joint than soldering
(ii) Joint is clean
(iii) Any metal can be brazed
(iv) Less distortion and residual stress
(v) The process can be done more quickly and more economically

Limitations:

(i) Limited size of parts.
(ii) Machining of the joint edges for getting the desired fit is costly.
(iii) Degree of skill required to perform the brazing operations is high.

Applications:

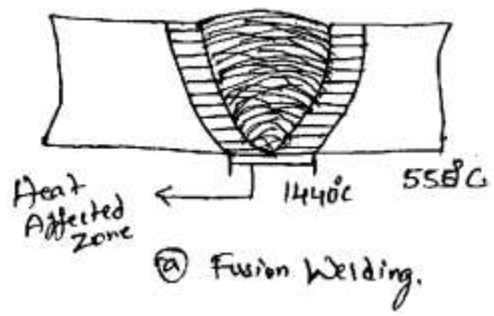
Brazing is used for the assembly of pipe fittings, carbide tips to tool shank, radiators, heat exchangers and the repair of castings.

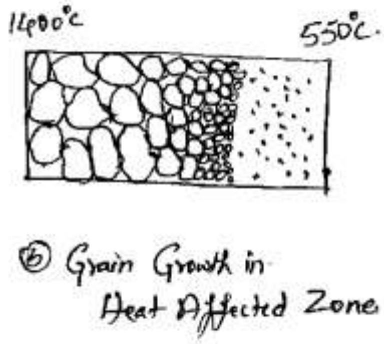
Uses of Brazing: Assembly of pipes to fittings, carbide tips to tools, radiators, heat exchangers, electrical parts and repair of castings. Leak-tight joints for pressurized and vacuum systems are readily joined by brazing.

Heat Affected Zone (HAZ):

Heat Affected Zone is the zone where in the base metal is metallurgically affected by the heat of welding, but is not melted.

Heat affected zone is the zone where the base metal is affected metallurgically due to the heat of welding. It is the region closed to the weld, where large thermal fluctuations are encountered due to the fusion welding. This leads to changes in mechanical properties and structure.





Heat Affected Zone contains three regions.

(a) The grain growth zone (1150°C)
(b) The grain refined zone (1150°C to 950°C)
(c) The transition zone (950°C to 750°C)

(a) The grain growth zone: It is immediately adjacent to the fusion zone. In this zone, parent metal has been heated to a temperature above upper critical temperature. This resulted in grain growth.

(b) The grain refined zone: Adjacent to the grain growth zone is the grain refined zone. In this zone, parent metal has been heated just above the transition temperature where grain refinement is completed.

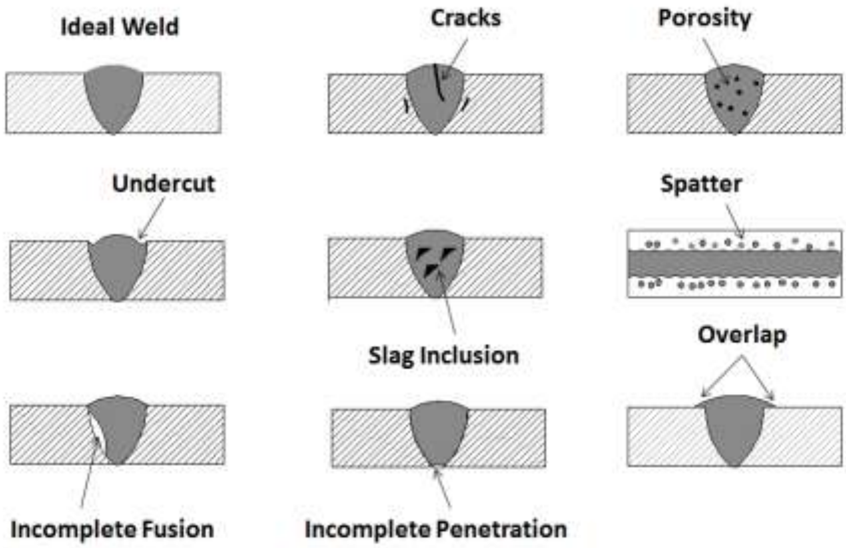
(c) The transition zone: In this zone, base metal temperature is below the transition temperature.

Welding Defects: Welding Defects can be defined as the irregularities formed in the given weld metal due to wrong welding process or incorrect welding patterns, etc. The defect may differ from the desired weld bead shape, size, and intended quality. Welding defects may occur either outside or inside the weld metal. Some of the defects may be allowed if the defects are under permissible limits but other defects such as cracks are never accepted.

Welding defects can be classified into two types as external and internal defects:

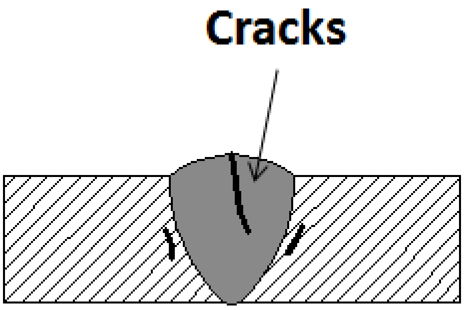
External Welding Defects:
1. Weld Crack
2. Undercut
3. Spatter
4. Porosity
5. Overlap
6. Crater

Internal Welding Defects:
1. Slag Inclusion
2. Incomplete Fusion
3. Necklace cracking
4. Incompletely filled groove or Incomplete penetration



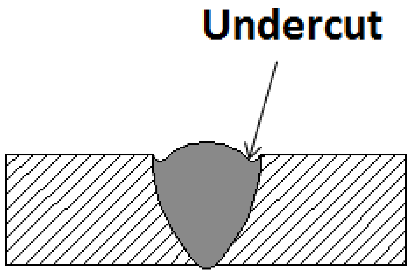
External Welding Defects
The various types of external defects with their causes and remedies are listed below:

1. Weld Crack
This is the most unwanted defect of all the other welding defects. Welding cracks can be present at the surface, inside of the weld material or at the heat affected zones.



Crack can also appear at different temperatures:
Hot Crack – It is more prominent during crystallization of weld joints where the temperature can rise more than 10,000-degree Celsius.
Cold Crack – This type of crack occurs at the end of the welding process where the temperature is quite low. Sometimes cold crack is visible several hours after welding or even after few days.
Causes Of Weld Crack:
1. Poor ductility of the given base metal.
2. The presence of residual stress can cause a crack on the weld metal.
3. The rigidity of the joint which makes it difficult to expand or contract the metals.
4. If there is high content on sulfur and carbon then also the cracks may appear.
5. Using hydrogen as a shielding gas while welding ferrous materials.
Remedies for Weld crack:
1. Using appropriate materials may decrease the chances of crack.
2. Preheating the weld and reducing the cooling speed joint helps in reducing crack.
3. Reduce the gap between the weld joints by using reasonable weld joints.
4. While welding releases the clamping force slowly which increases fill to capacity of welding material.

2. Undercut



When the base of metal melts away from the weld zone, then a groove is formed in the shape of a notch, then this type of defect is known as Undercut. It reduces the fatigue strength of the joint.

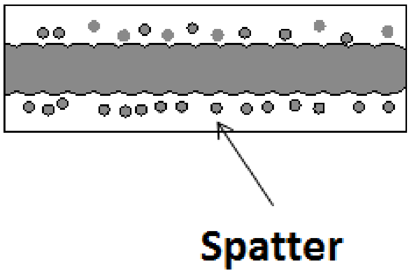
Causes of Undercut:

1. If the arc voltage is very high then this defect may occur.
2. If we use the wrong electrode or if the angle of the electrode is wrong, then also the defect may form.
3. Using a large electrode is also not advisable.
4. High electrode speed is also one of the reasons for this defect.

Remedies for Undercut:

1. Reduce the arc length or lower the arc voltage.
2. Keep the electrode angle from 30 to 45 degree with the standing leg.
3. The diameter of the electrode should be small.
4. Reduce the travel speed of the electrode.

3. Spatter



When some metal drops are expelled from the weld and remain stuck to the surface, then this defect is known as Spatter.

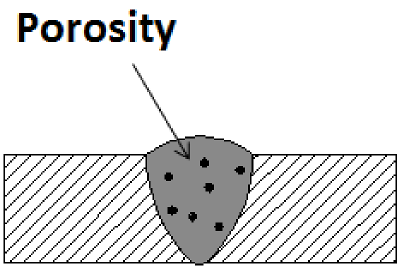
Causes Of Spatter:

1. High Welding current can cause this defect.
2. The longer the arc the more chances of getting this defect.
3. Incorrect polarity.
4. Improper gas shielded may also cause this defect.

Remedies for Spatter:

1. Reducing the arc length and welding current
2. Using the right polarity and according to the conditions of the welding.
3. Increasing the plate angle and using proper gas shielding.

4. Porosity

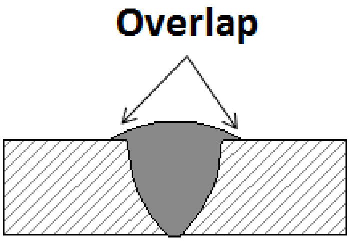


Porosity in the condition in which the gas or small bubbles gets trapped in the welded zone.

Causes of Porosity:
1. It occurs when the electrode is not coated properly.
2. Using a longer arc may also increase its chances.
3. Increased welding currents.
4. Rust or oil on the welding surface.

Remedies for porosity:
1. Proper selection of the electrode.
2. Decreasing the welding current.
3. Using smaller arc and slowing the process to allow the gases to escape.
4. Remove rust or oil from the surface and use a proper technique.

5. Overlap



When the weld face extends beyond the weld toe, then this defect occurs. In this condition the weld metal rolls and forms an angle less than 90 degrees.

Causes of Overlap:
1. Improper welding technique.
2. By using large electrodes this defect may occur.
3. High welding current

Remedies for Overlap:
1. Using a proper technique for welding.
2. Use small electrode.
3. Less welding current.

6. Crater

It occurs when the crater is not filled before the arc is broken, which causes the outer edges to cool faster than the crater. This causes a stress and then crack is formed.

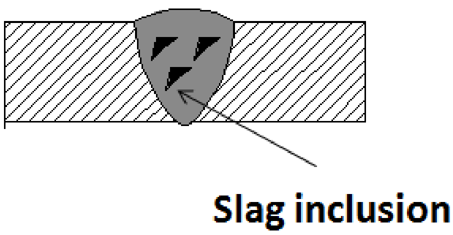
Causes of the crater:
1. Incorrect torch angle.
2. Use of large electrode:
3. Improper welding technique

Remedies for crater:
1. Using a proper torch angle may reduce the stress on the metal
2. Using a small electrode may also decrease the crater.
3. Use a proper technique.

Internal Welding Defects

The various types of internal welding defects with their causes and remedies are listed below:

1. Slag Inclusion



If there is any slag in the weld, then it affects the toughness and metal weldability of the given material. This decreases the structural performance of the weld material. Slag is formed on the surface of the weld or between the welding turns.

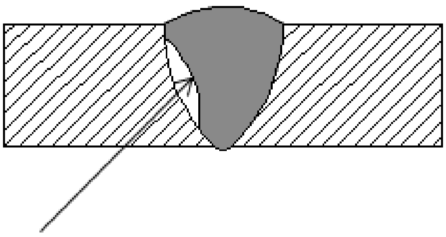
Causes Of Slag:

1. Slag is formed if the welding current density is very small, as it does not provide the required amount of heat for melting the metal surface.
2. If the welding speed is too fast then also slag may occur.
3. If the edge of the weld surface is not cleaned properly then also slag may form.
4. Improper welding angle and travel rate of welding rod.

Remedies for Slag Inclusion:

1. Increase the current density
2. Adjust the welding speed so that the slag and weld pool do not mix with each other.
3. Clean the weld edges and remove the slags of previous weld layers
4. Have a proper electrode angle and travel rate.

2. Incomplete Fusion



Incomplete Fusion

Causes of Incomplete fusion:

1. It occurs because of the low heat input.
2. When the weld pool is very large and runs ahead of the arc.
3. When the angle of the joint is too low.
4. Incorrect electrode and torch angle may also lead to incomplete fusion.
5. Unproper bead position.

Remedies for Incomplete Fusion:

1. Increasing the welding current and decreasing the travel speed helps in removing the chances of incomplete fusion.
2. Reducing the deposition rate.
3. Increasing the joint angle.
4. Try to position the electrode and torch angle properly so that the edges of the plate melt away.
5. Positioning the bead properly so that the sharp edges with other beads can be avoided.

3. Necklace Cracking

It occurs in the use of electron beam welding where the weld does not penetrate properly. Therefore, the molten metal does not flow into the cavity and results in a cracking known as "Necklace Cracking".

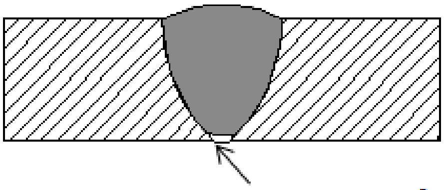
Causes of Necklace Cracking:

1. Improper welding technique.
2. It occurs in materials such as nickel base alloys, stainless steel, carbon steels and Tin alloys.
3. Using high speed of electron beam welding

Remedies for Necklace Cracking:

1. Using a proper welding technique reduce the chances of necklace cracking.
2. Using proper materials for welding.
3. Using a constant speed during the welding process.
3. Improper welding technique

4. Incompletely Filled Groove or Incomplete Penetration



Incomplete Penetration

These defects occur only in the butt welds where the groove of the metal is not filled completely. It is also called as incomplete penetration defect.

Causes of an Incomplete filled groove are:

1. Less deposition of the weld metal
2. Use of improper size of the electrode
3. Improper welding technique

Remedies for Incomplete filled groove are:

1. More deposition of the weld metal.
2. Use a proper size of the electrode.
3. By using a proper welding technique.

Testing and Inspection of Welded Joints:

Testing and inspection of welded joints is done on the same lines as for castings. The tests fall under two categories: Destructive testing and Non-destructive testing.

Destructive Testing: These tests are done on a sample to improve the design of the weld, welding technique etc. and to know the mechanical properties of the weldment. These mechanical tests included: Tensile test, Bend test, Impact strength test, Hardness test and relative elongation test. The shape and size of the test specimen are selected to comply with state standards.

Non – Destructive Testing (NDT): The tests under this category include:

1. Visual Inspection: Visual Inspection of the weld and checking of its dimensions can reveal: shape of profile, uniformity of surface, undercuts of surface, undercuts, surface cavities and slag inclusions, cracks, porosity, unfilled craters etc.

2. Hydraulic tests (pressure tests) are applied to weldments that are to operate under pressure.

3. Air pressure tests are done to check the air tightness of the work.

The other NDT include:

→ Radiographic inspection of the weld (X-ray and gama-ray testing) will reveal such defects as porosity, blowholes, cracks, poor fusion and slag inclusion.
→ Fluorescent penetrant inspection to reveal fine surface cracks.
→ Magnetic inspection reveals fine cracks and pores in the weld.
→ Ammonia penetrant test: This is a leak test. The welded vessel is filled with compressed air to which 1% ammonia has been added. The welded joint is then covered with paper impregnated with a 5% solution of mercuric nitrate. Black spots appear on the paper in case of leakage.

Comparison among Welding, Brazing and Soldering:

Welding	Soldering	Brazing
1. In welding process fusion is obtained by heat and or pressure.	1. In Soldering the joint is obtained by means of filler material whose melting point is less than 450°C and less than the melting point of base metal.	1. In brazing the joint is obtained by means of filler material whose melting point is above the 450°C and less than the melting temperature of base metal.
2. The strength of the joint is highest comparing to soldering and brazing.	2. The soldering joints are weakest among the soldering, welding and brazing.	2. The brazed joints are stronger than soldered joint but weaker than welded joints.
3. The joint strength at times may be equal to even greater than the strength of the base metals.	3. The joint strength depends upon the adhesive qualities of filler material and can never reach the strength of base metal.	3. The joint strength depends upon the adhesive qualities of filler material and can never reach the strength of base metal.
4. The filler material may or may not be used.	4. The filler material is essentially used because joint is made by filler material only.	4. The filler material is essentially used because joint is made by filler material only.
5. The composition of filler metal is normally same as that of base metal. (the metal to be welded)	5. Essentially filler metals are alloys of lead and tin	5. he filler metals are alloys of copper (e.g. copper zinc alloys and copper silver alloys)
6. Welded joints can withstand high temperature.	6. Soldered joints are not suitable for high temperature service because of lower melting point of the filler metal.	6. Brazed joints are also not suitable for high temperature service because of lower melting point of filler metal.
7. The process cannot joint dissimilar metals which are insoluble in other.	7. The process can join dissimilar metals which are insoluble in each other.	7. The process can join dissimilar metals which are insoluble in each other.
8. The parent metals are heated to the melting temperature, so welding is likely to cause the metallurgical damage and change in the properties.	8. Heating of parent metal is negligible to cause any change in their structure and properties.	8. Heating of parent metal is negligible to cause any change in their structure and properties.
9. Welding has wide applications in construction and maintenance of boilers, pressure vessels, tanks bridges, building constructions, cutting tools dies, and furnaces.	9. Soldering is widely used in joining small assemblies, electric and electronics parts.	9. Brazing is used for joining electrical parts, joining carbide tips to tools, heat exchangers, radiators etc…

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UNIT 3 – Metal Forming Processes

- **Introduction**
- **Classification Of Metal Forming Process**
- **Differences Between Hot Working And Cold Working**
- **Recrystallisation**
- **Advantages Of Hot Working Processes**
- **Limitations**
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- **Bending**
- **Forming**
  - **Stretch Forming**
- **Embossing**
- **Drawing**
- **Tube Drawing**
- **Coining**
- **Spinning**

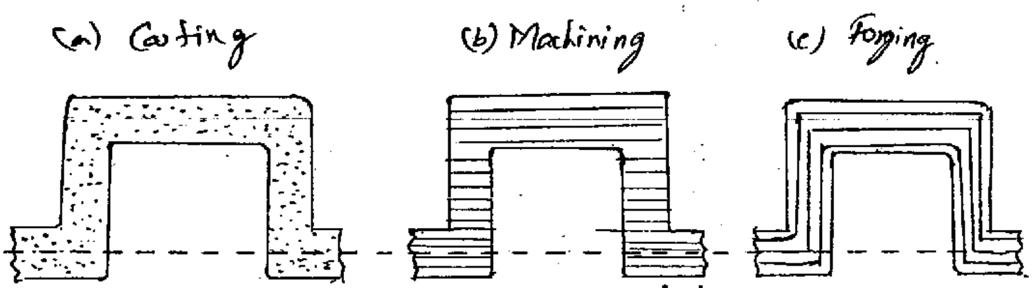
Introduction:

Forging processes are primary manufacturing processes. In these processes metals are deformed to get desired shape and size. The necessary deformation in metals can be achieved by application of large amount of mechanical forces only or by heating the metal and then applying comparatively less forces. The desired shape and size is obtained by means of set of tools called dies which may be open or closed dies. The stresses induced during the process are greater than yield strength but less than fracture strength.

During plastic deformation metal is said to flow plastically. The crystals and grains of metals get elongated in the direction of flow of metal. So the mechanically worked metals have better strength in specific direction. The metal is strong when stresses are acting across the direction of grain flow line. The metal of course would be comparatively weak along the flow lines. The wastage of material is negligible or there may be no wastage as the metal is deformed to get desired shape and size.

Compare three methods of manufacturing a crank shaft. Casting, machining and forging (hot working process):

(i) The crank shaft produced by castings has no grain flow so has the poorest mechanical properties.
(ii) The crank shaft made by machining has interrupted fibre flow of metal so the mechanical properties of this shaft will be proper than those of forging.
(iii) The third figure shows the crank shaft made by forging process. Here the fibre of metal is not interrupted and is continous along the entire length of the shaft. Hence it will develop superior mechanical properties.



Comparison of grain flow in Various Manufacturing processes.

It is clear from above discussion that components manufactured from metal forming processes will have higher strength and mechanical properties as compared to casting and machining processes. Direction of grain flow lines can be controlled in metal forming process and these components will develop maximum mechanical properties in application where components are subjected to impact or fatigue loading. For static loading direction of grain flow lines is not so important.

Classification of Metal Forming Processes:

On the basis of heat applied forming process can be classified into two broad categories:

1. Hot Working Processes.
2. Cold Working Processes.

(1) Hot working is the plastic deformation of metals above recrystallisation temperatures.
(2) Cold working is the plastic deformation of metals below recrystallisation temperatures.

METAL FORMING PROCESSES

Hot Working

1. Rolling
2. Extrusion
3. Forging
4. Hot Drawing

Cold Working

1. Wire Drawing
2. Cold Extrusion
3. Cold Rolling
4. Cold Forging
5. Sheet Metal Processes

Differences between Hot Working and Cold Working:

Hot Working	Cold Working
1. Hot working is done at a temperature above recrystallisation but below melting point. It can be therefore be regarded as a simultaneous process of deformation and recovery.	1. Cold working is done at temperature below recrystalli-sation temperature. So no appreciable recovery can take place during deformation.
2. Hardening due to plastic deformation is completely, eliminated by recovery and recrystallisation.	2. Hardening is not eliminated since working is done at a temperature below recrystallisation.
3. Mechanical properties such as elongation, reduction of area and impact values are improved. Ultimate tensile strength, yield point, fatigue strength, hardness are not affected by hot working.	3. Cold working decreases elongation, reduction of area. Increases ultimate tensile strength, yield point and hardness.
4. Surface finish of hot worked metal is not nearly as good as with cold working because of oxidation and scaling.	4. Good surface finish is obtained.
5. Refinement of crystals occurs.	5. Crystallisation does not occur. Grains are only elongated.
6. Cracks and blowholes are welded up.	6. Possibility of crack formation and propagation is great.
7. Internal or residual stresses are not developed in the metal.	7. Internal and residual stresses ate developed in the metal.
8. Oxide forms rapidly on metal surface.	8. Cold parts posses less durability.
9. Less force is required.	9. Higher forces are required for deformation.
10. Equipment used in hot working is light.	10. More powerful and heavier equipments are required for cold working.
11. Handling and maintenance of hot metal is difficult and troublesome.	11. Easier to handle cold parts.

12. Hot working processes: (a) Hot forging (b) Hot rolling (c) Hot spinning (d) Hot extrusion (e) Welded pipe and tube manufacturing (f) Roll piercing (g) Hot drawing	12. Cold working processes: (a) Cold rolling (b) Cold extrusion (c) Press work (i) Drawing (ii) Squeezing (iii) Bending (iv) Shearing

Recrystallisation:

Recrystallisation temperature is temperature at which entirely new crystals or grains are formed and old grain structure is destroyed. Recrystallisation varies for different materials. The following table shows recrystallisation temperature of some of the metals. It is generally one-half to one-third for most of the metals. It also depends upon other variables like if the material is already cold worked and there is large plastic deformation, material would have low recrystallisation temperature. This is because after cold working and deformation metal have more stored energy in form of vacancies and dislocation. With this energy available it takes less thermal energy for atoms to rearrange themselves. Therefore, recrystallisation can occur at lower temperatures.

Metal	**Temperature in (°C)**
Aluminium	150°C
Copper	200°C
Gold	200°C
Iron	450°C
Silver	200°C
Nickel	590°C
Zinc	At room temperature
Lead	Below room temperature
Tin	Below room temperature

The dividing line between hot working and cold working processes is recrystallisation temperature. Hot working does not necessarily mean high absolute temperature. The process may be carried out with or without actual heating. For example, lead and tin have recrystallisation temperature below room temperature. So mechanical working of these metals at room temperature is always hot working process. For steels recrystallisation temperature is around 1000°C and working below this temperature is still a cold working process.

Advantages of Hot working Processes:

1. As the metal is above the recrystallisation temperature large deformation can be obtained because there is no strain hardening.
2. Because of grain refinement, ductility and toughness are improved, strength is increased and greater homogeneity is developed in metal.
3. At high temperature metals have high ductility so less force is required to achieve the necessary deformation.
4. Porosity in the ingot is eliminated to a large extent.
5. Directional properties resulting from grain flow are obtained.
6. Even brittle materials can be hot worked.

Limitations:

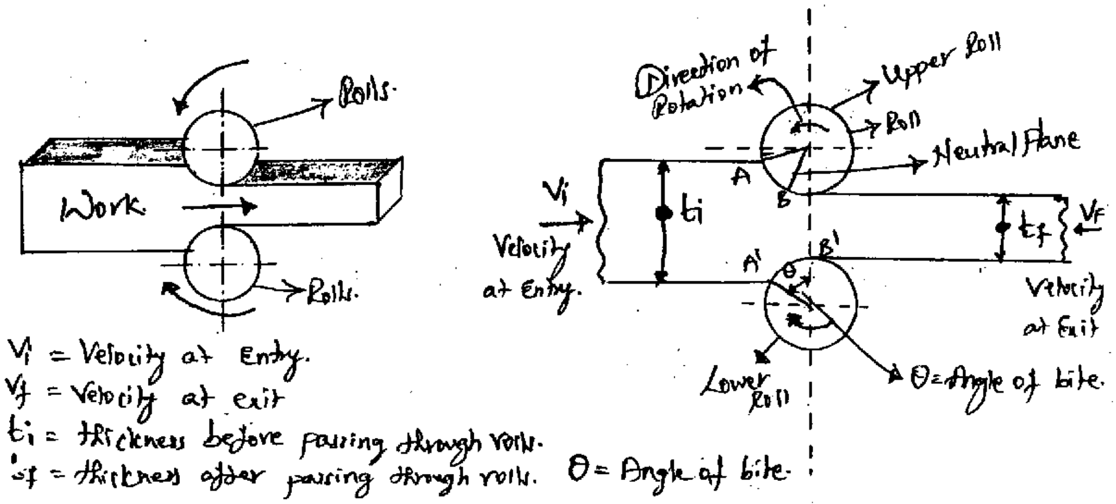
1. There is rapid oxidation or scaling of surfaces due to high temperature of metal which results in poor surface finish.
2. Because of the thermal expansion of metal dimension accuracy cannot be achieved.
3. Hot working equipment handling and maintenance costs are high.
4. Some metal cannot be hot worked as they become brittle at high temperatures.

Rolling:

Rolling is the process of compressing the metal by passing it between two revolving cylinders called rolls. As the metal is compressed its cross section area is reduced and length is increased.

Rolling is normally a hot working process unless specifically mentioned as cold working. The starting material is the moulded ingot which is rolled into intermediate shapes like blooms, billets and slabs. These intermediate shapes are rolled further into plates, sheets, bars, structural shapes, I, L, T or channel section.

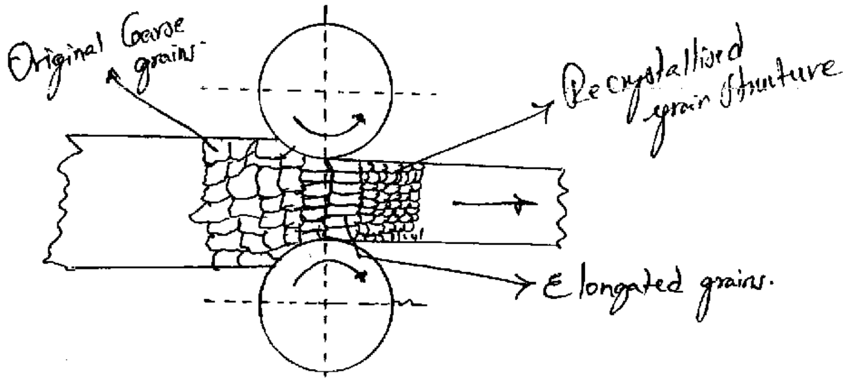
The rolling process is explained in below. Heated metal is passed between two rolls that rotate in opposite direction; the gap between the rolls is some what less than the thickness of metal at entrance.



Following are the characteristics of rolling process:

1. The amount of thickness that can be reduced in single pass between a given pair of rolls depends upon the friction between the roll surface and metal. Rougher rolls would be able to achieve greater reduction than smoother rolls, but the roll surface gets embedded into rolled metal and produces rough surface. The reduction that can be achieved with given pair of rolls in single pass is known as angle of bite.
2. In the process of rolling, the speed of metal is continuously changing between the entry and exit of roll where as roll speed remains constant. Since cross-sectional area is decreasing metal enters the rolls with a speed less than speed of rolls and exits from rolls traveling at a higher speed than it enters. At a point between contacts length A and B as shown in above figure the metal speed is same as the roll speed. This is designated as neutral plane.
3. During the rolling of ingot, the volume of the metal that enters rolling mill is same as that leaving except in initial passes when there might be some loss due to filling of voids and cavities.

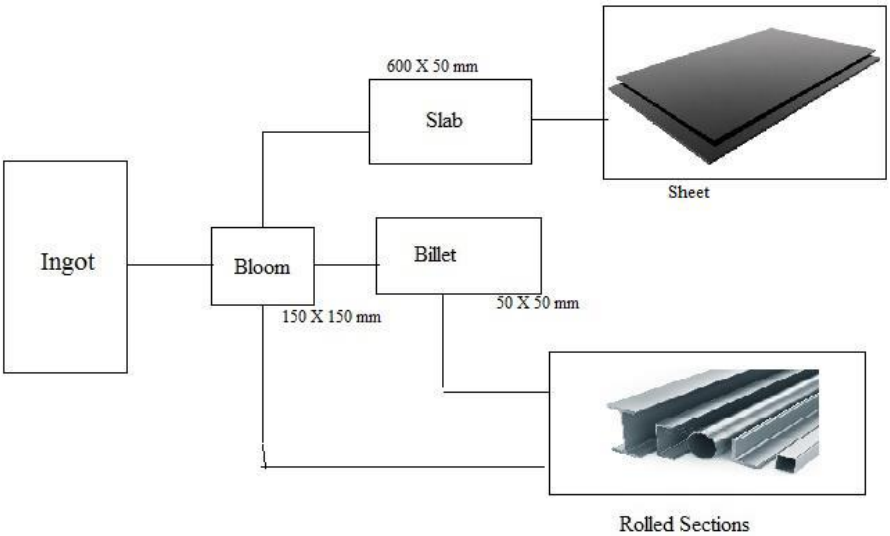
The following figure shows, how grain structure is refined during rolling by recrystallisation. Original coarse grains are elongated by rolling action. Because of high temperature recrystallisation starts and small grains begin to form.



Terminology Associated with Rolled Products:

1. **Ingot:** This is the raw material used in rolling. This is obtained by pouring molten metal into ingot moulds having standard dimension. The ingot is rolled in intermediate shapes like slabs, billets and blooms.
2. **Slab:** The standard dimensions of slab are 50 to 150mm thickness and 600 to 1500mm width.
3. **Bloom:** Blooms have square cross-section and are small than bloom. They can have any cross-section of from (38.1 X 38.1mm) upto the size of bloom. They are further rolled into shapes such as rounds, rods or bars.
4. **Plate sheets and Strips:** Plates, sheets and strips are obtained by further rolling the slab with flat rolls.

Production Sequence in Getting Rolled Products:



The ingot is rolled to intermediate shapes – blooms & slabs. These blooms, billets and slabs are further rolled into plate sheets, bar stock and structural shapes as shown in above figure.

Hot and Cold Rolling:

In hot rolling the metal is fed between rolls after being heated above the recrystallisation temperature. This leads to grain refinement, thereby mechanical properties are improved. During hot rolling, the work hardening does not occur and coefficient of friction between the rolls and the metal is higher. Heavy reduction in area of the work piece can be obtained. Hot rolled parts do not have a good surface finish due to scaling.

In cold rolling, the metal is fed to the rolls when it is below its recrystallisation temperature. This results in elongation of grain structure. The metal shows work hardening effect after cold rolling. This increases harness and decreases the ductility of the metal. Heavy reductions are not possible. The coefficient of friction between the rolls and the metal is lower. The cold rolled a surface is smooth and oxide free.

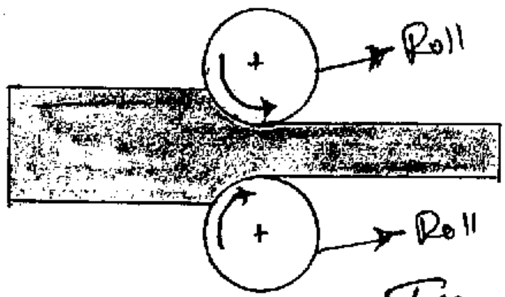
Classification of Rolling Mills:

Rolling mills are classified according to the number and arrangement of rolls in a stand. They are as follows:

1. Two – high rolling mill
2. Three – high rolling mill } Generally used for Hot Rolling of Metals
3. Four – high rolling mill
4. Tandem rolling mill
5. Cluster rolling mill } Generally used for Cold Rolling of Metals

1. Two – High Rolling Mill:

It consists of two heavy horizontal rolls placed one over the other. The space between the rolls can be adjusted by raising or lowering the upper roll. The position of the power roll is fixed. The rolls rotate in opposite direction. The work can be rolled by feeding from one direction only. This is called non – reversing mill.

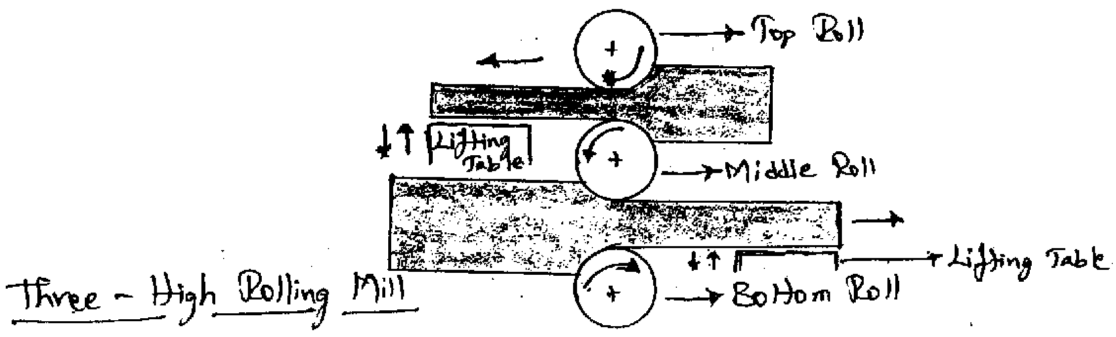


Two – High Rolling Mill

There is another type of two – high mill, which incorporates a drive mechanism that can reverse the direction of rotation of the rolls. This is knows as two – high reversing mill. In this, the rolled metal is passed backward and forth through several times. This type is used in blooming and slabbing mills and for rough work.

2. Three – High Rolling Mill:

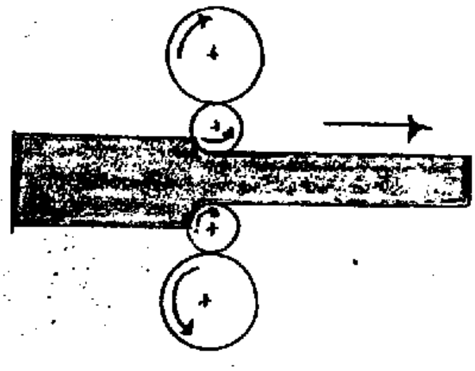
It consists of three horizontal rolls placed one over the other. The upper and lower rolls rotate in the same direction; where as the intermediate roll rotates in direction opposite to the outer roll.



First of all the work piece passes through the bottom and the middle rolls and then returning between the middle and top rolls so that the thickness is reduced at each pass. Mechanically operated lifting tables are used which move vertically on either side of the roll stand. It may be used ot make plates or sections.

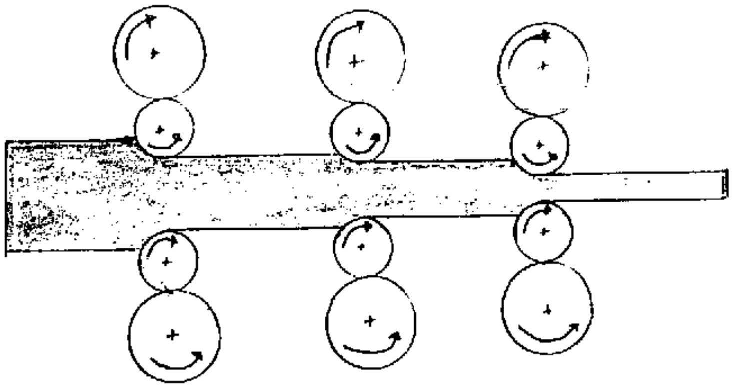
3. Four – High Rolling Mill:

It consist of four horizontal rolls, two of smaller diameter and two of large diameter. The bigger rolls are called back up rolls because they reinforce the smaller rolls to maximize roll deflection there by minimizing the tendency of producing plates and sheets thicker at the centre than at the two outer edges. The two smaller rolls are called work rolls. It is used for both hot and cold rolling of plates and sheets.



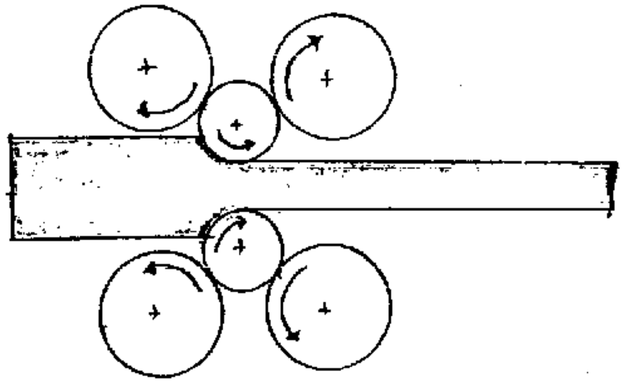
4. Tandem Rolling Mill:

It is set of two or three stands of rolls set in parallel alignment so that a continous pass may be made through each one successively without change of direction of material.



5. Cluster Rolling Mill:

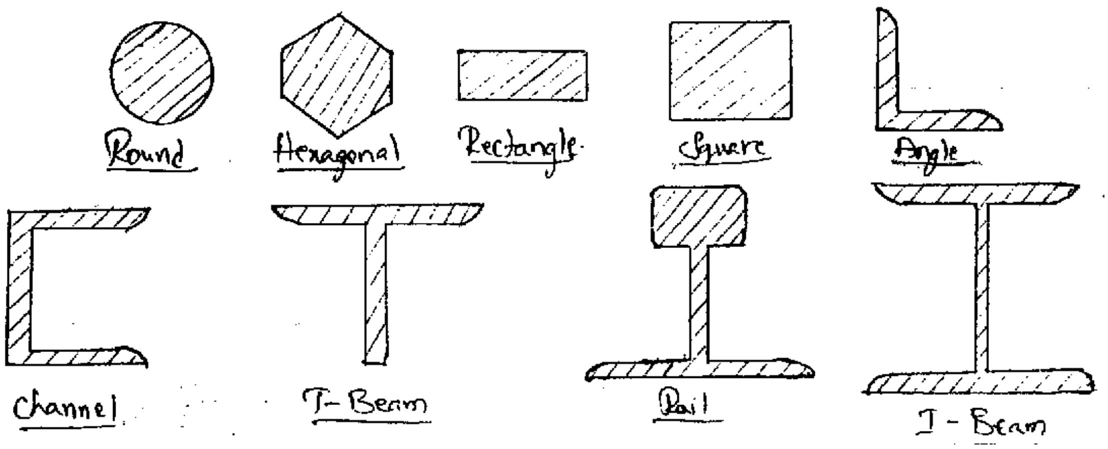
It consists of two working rolls of smaller diameter and one or more backup rolls of larger diameter. The number of backup rolls may go up to 20 or more, depending on the amount of support needed for the working rolls during the operation. Cold rolling is employed for providing a smooth and bright surface finish.



Range of Rolled Products:

The whole range of rolled products can be divided into the following:

(a) **Structural Shapes or Sections:** This includes section like round square, hexagonal bars channels, H and I beams and special section like rail sections. The following figure shows some structural shapes.
(b) **Plates and Sheets:** Plates and sheets are produced by rolling.
(c) **Special Purpose Rolled Products:** These include rings, balls, wheels and ribbed tubes.



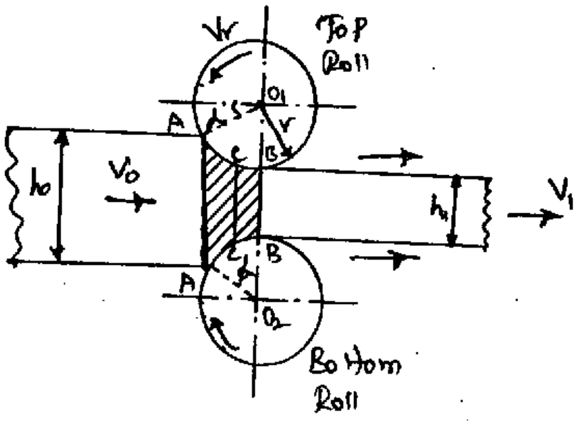
Lubrication in Rolling Process:

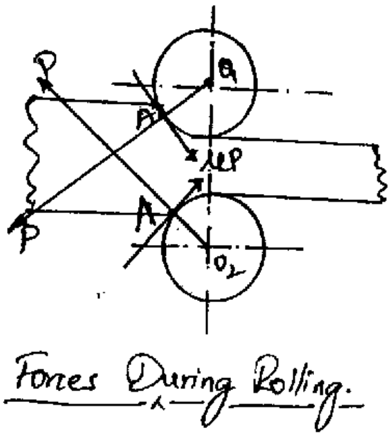
Lubrication in rolling process protects the rolls against wear, reduces friction and allows smooth flow of metal between rolls. It also protects the metal surface from scratching and peeling.

The selection of lubricant depends on
(i) Material
(ii) Roll Pressure
(iii) Speed of rolling.

The most commonly used lubricants are
(i) High penetrating and wetting soluble oils
(ii) Synthetic soluble
(iii) Oils with excellent polarity.

Mechanism of Rolling and Forces during Rolling:





The above figure shows a schematic diagram of the rolling process. The metal contacts each of the two rolls along the arc AB, which is known as the arc of contact. The arc corresponds to the central angle , called the "angle of contact or bite". The process of metal rolling is made possible by the friction that occurs between the contact surfaces of the rolls and the part being rolled. At the moment of bite, two forces act on the metal from the side of each roll, normal force P and the tangential for μP, where μ is the co-efficient of friction between the metal and the roll surfaces. The part would be dragged in if the resultant of horizontal component of the normal force P and tangential force (frictional force) μP is directed in that direction.

In the limiting case,

$$P \sin \alpha = \mu P \cos \alpha$$
$$\mu = \tan \alpha$$
$$\alpha = \tan^{-1} \mu$$

Or

If α is greater than $\tan^{-1} \mu$, the metal would not enter the space between the rolls automatically, that is, unaided.

The maximum permissible angle of bite depends upon the valve of 'μ' which in turn depends upon the materials of the rolls and the job being rolled, the roughness of their surfaces, and the rolling temperatures and speed.

In hot rolling, the primary purpose is to reduce the section and hence the maximum possible reduction is desired. So, the value of and hence of μ should be greater. In hot rolling, lubrication is generally not necessary. On the other hand, on primary reduction rolling mills such as blooming or rough rolling mills for structural elements, the rolls may sometimes "ragged" to increase μ. Ragging is the process of making certain fine grooves on the surface of the roll to increase the friction. In cold rolling, the rolling loads are very high; hence μ should not be much. Besides, cold rolling being a finishing operation, rough rolls will impair the surface of the cold rolled product. Due to this, rolls for cold rolling are ground and lubricants are also used to reduce μ.

The usual values of biting angle are:

α = 3° to 4° for cold rolling of steel and other metals with lubrication on well-ground rolls.
= 6° to 8° for cold rolling of steel and other metals with lubrication on rough rolls.
= 18° to 22° for hot rolling steel sheets

= 20° to 22° for hot rolling aluminium at 350°C
= 28° to 30° for hot rolling steel (blooms and billets) in ragged or well roughed rolls.

Defects in Rolled Products

The various defects in rolled products are as follows:

1. **Edge cracking:** This defect occurs in plate or slabs because of either limited ductility or metal or uneven deformation, especially at the edges.
2. **Folds:** These defects occur during plate rolling when reduction per pass is very small.
3. **Lamination:** These are small cracks, which develop when reduction in thickness is quite high.
4. **Alligatoring:** This defect takes place in rolling of slabs of aluminium alloys where the work piece splits along a horizontal plane on exit.

Stamping (metalworking)

Stamping includes a variety of sheet-metal forming manufacturing processes, such as punching using a machine press or stamping press, blanking, embossing, bending, flanging, and coining. This could be a single stage operation where every stroke of the press produce the desired form on the sheet metal part, or could occur through a series of stages. The process is usually carried out on sheet metal, but can also be used on other materials, such as polystyrene.

Operations
- Bending
- Blanking
- Coining
- Drawing
- Piercing

Forming Processes (Mechanical Working Processes):

Forming processes or mechanical working processes are primary manufacturing processes. In these processes metals are deformed to get desired shape and size. The necessary deformation can be achieved by application of large amount of mechanical force only or by heating the metal and then applying less force. The desired shape and size is obtained by means of set of tools called dies which may be open or closed dies. The following figure shows a closed die. The stresses induced during the process are greater than yield strength but less than fracture strength.

Forming processes are very economical processes as they involve minimum amount of material wastage and result in faster production. The materials processes by forming processes develop superior mechanical properties like strength, hardness and toughness etc… Ductility is quite desirable property of materials in forming processes.

Forming processes can be grouped into two categories:
1. Cold working processes
2. Hot working processes

If the working temperature is lower than recrystallization temperature then process is termed as cold working process.

When the working temperature is above recrystallization temperature then process is termed as hot working process.

Some of the metals forming processes are:

- Rolling
- Extrusion
- Forging
- Wire drawing
- Sheet metal operations

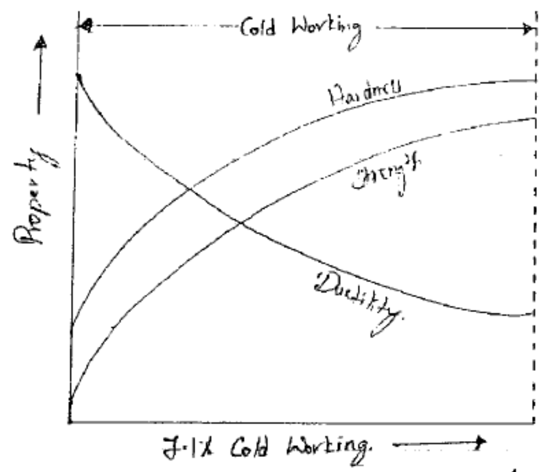
The applications of metal forming processes include structural shapes, tooth paste tubes, cans, pipe and tube manufacturing, screws, rivets. Sheet metal operation applications include car bodies, ship building, air craft bodies, boilers, toys, containers for edibles etc.

Cold Working Processes:

Cold working processes come under the category of metal forming processes and can be defined as processes in which desired shape and size are obtained through the plastic deformation of material below recrystallisation temperature. The stresses induced during the process are greater than yield strength but less than fracture strength of the material. In other words we may say that stresses are intentionally exceeded to shape of components.

Following are the salient characteristics of cold working processes:

1. Cold working increases the strength and hardness of material. This increase in strength is called strain hardening. Strain hardening is of prime importance to the design engineer as it permits the use of smaller parts with great strength.
2. Surface finish and dimensional accuracy, obtained in cold working processes is quite good.
3. During cold working process hardness and strength is increased and ductility is decreased. Ductility is quite useful property in metal forming processes. The amount of cold work that can be done on the metal depends on the ductility. Higher the ductility of metal mote it is able to be cold worked.
4. The amount of deformation withstand by pure metal is higher as compared to metal having alloys because alloys increase the tendency and rapidly of strain hardening which reduces ductility.
5. Metals having large grain structure are more ductile than smaller grained metals.



Cause of Strain Hardening:

It has been shown that only 85 to 90% of the energy absorbed by material during cold working process is accountable in the form of heat, sound and elastic strain energy. The remaining 10 to 15% of energy or work done on the material goes to change the molecular or grain structure of the material by atomic dislocation, fragmentation or lattice distortion or combination of three phenomena. Thus the material being worked after elastic limit becomes stronger and harder. This could be possible explanation for the phenomena of work hardening or strain hardening.

Residual Stresses:

During the cold working processes internal or residual stresses are developed. To remove these undesirable stresses, the metal is reheated slightly below the recrystallization range temperature. In this range stresses are eliminated without appreciable change in grain structure because heating into recrystalline range eliminates the effects of cold working.

Advantages of Cold Working Processes:

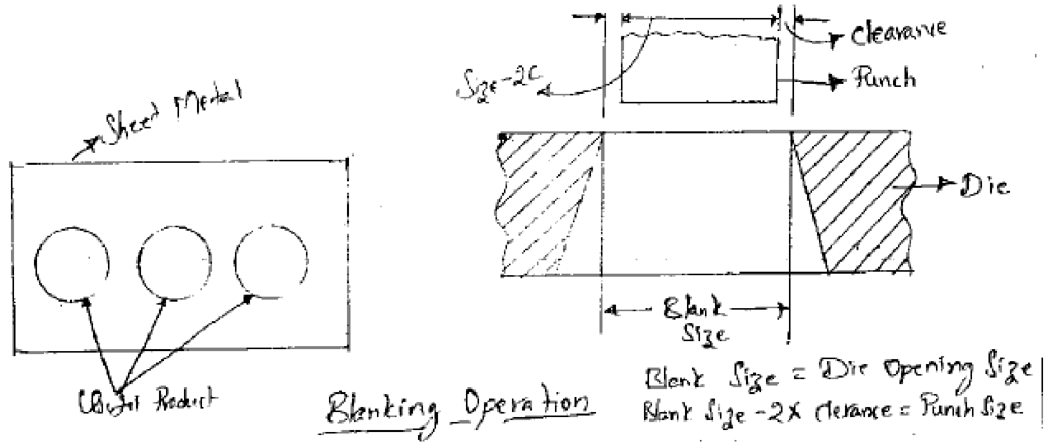
1. Cold working increases strength and hardness by strain hardening at the expense of ductility which is useful in some applications.
2. Good surface finish is achieved because no oxides are formed during cold working processes.
3. Better dimensional accuracy is achieved.
4. It is easier to handle cold metals and economical for some cases like manufacturing small size components.

Limitations of Cold Working Processes:

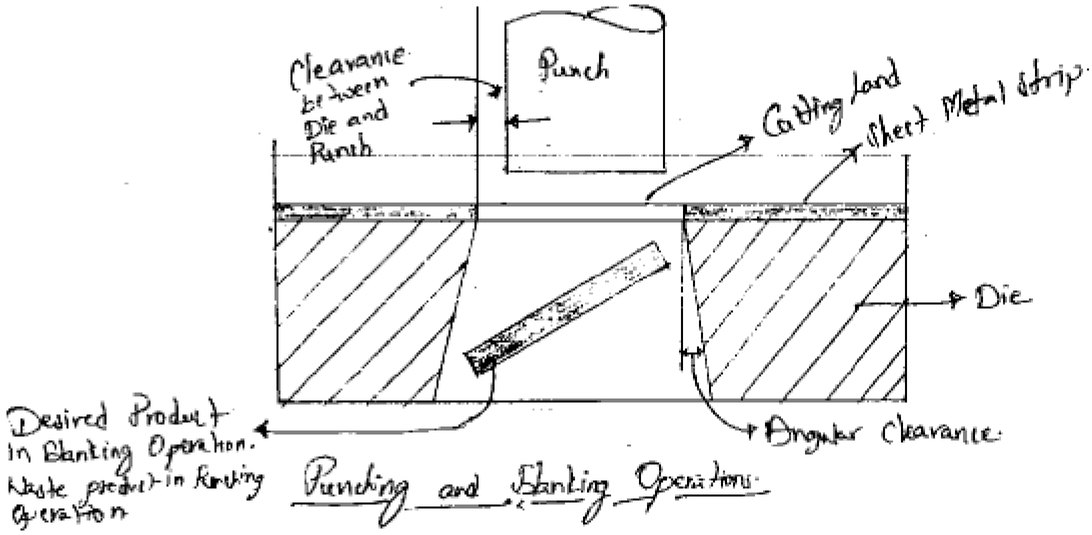
1. Since the metal has highly yield strength and low ductility at lower temperature the amount of deformation that can be achieved is less, further deformation can be achieved only after annealing.
2. The material gets strain hardened and internal stresses are developed which remains unless they are removed by annealing.
3. The ductility of metal decreases. After cold working ir becomes brittle if it is over worked.

Blanking:

Blanking is the operation of cutting out flat shapes from sheet metal strip. The removed portion is called blank which is required product of the operation and metal with hole left behind discarded as waste. Blanking is usually first operation and blank is further processed to produce desired part. Blanking is identical to the punching except that in blanking removed portion is desired product where as in punching sheet with the hole is desired product.



- The punch and die are made of suitable hard and strong material such as hardened high carbon steel, high chromium oil hardening steel, or tungsten carbide.
- In blanking operation die opening size equals the blank size and punch size is obtained by subtracting clearance form die opening size.



Following are the terminologies associated with punch and die setup in shearing:

1. Angular clearance: The angular clearance is shown in above figure.

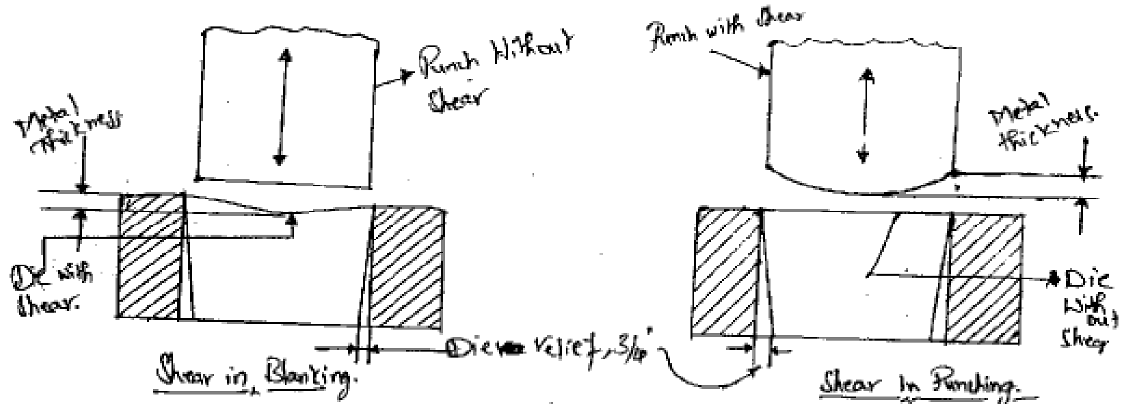
In blanking and punching operation first the material is elastically deformed and then plastically and finally removed from the sheet metal strip. After the final breaking, the size of blank will slightly increase because of spring back and this will make the blank to jam in die. It is usual practice to provide angular clearance on dies to avoid sticking of blank to die face. The angular clearance or draft provided depends on the material, thickness and shape of stock used. For thicker and softer materials generally higher angular clearances are provided. The normal value is from 0.25° to 0.75° per side but occasionally a value as high as 2° may be used.

2. Cutting land: The diameter of die at the top keeps on increasing after every sharpening because of the provision of angular clearance. In order to maintain the die size as per design it is a usual practice to provide straight portion along with angular clearance. This is called die land or cutting land. The length of cutting land is about 3 mm for sheets which are less than 3 mm thick. For greater thicknesses die land same as the material thickness has been found to be a good practice.

3. Stripper: During shearing operation after the final breaking, the hole size of metal strip will slightly decrease because of spring back and strip will cling tightly to the punch. A stripper therefore is provided to remove the metal strip from sides of punch as punch returns upward.

Application of shear in Blanking and Punching and its use:

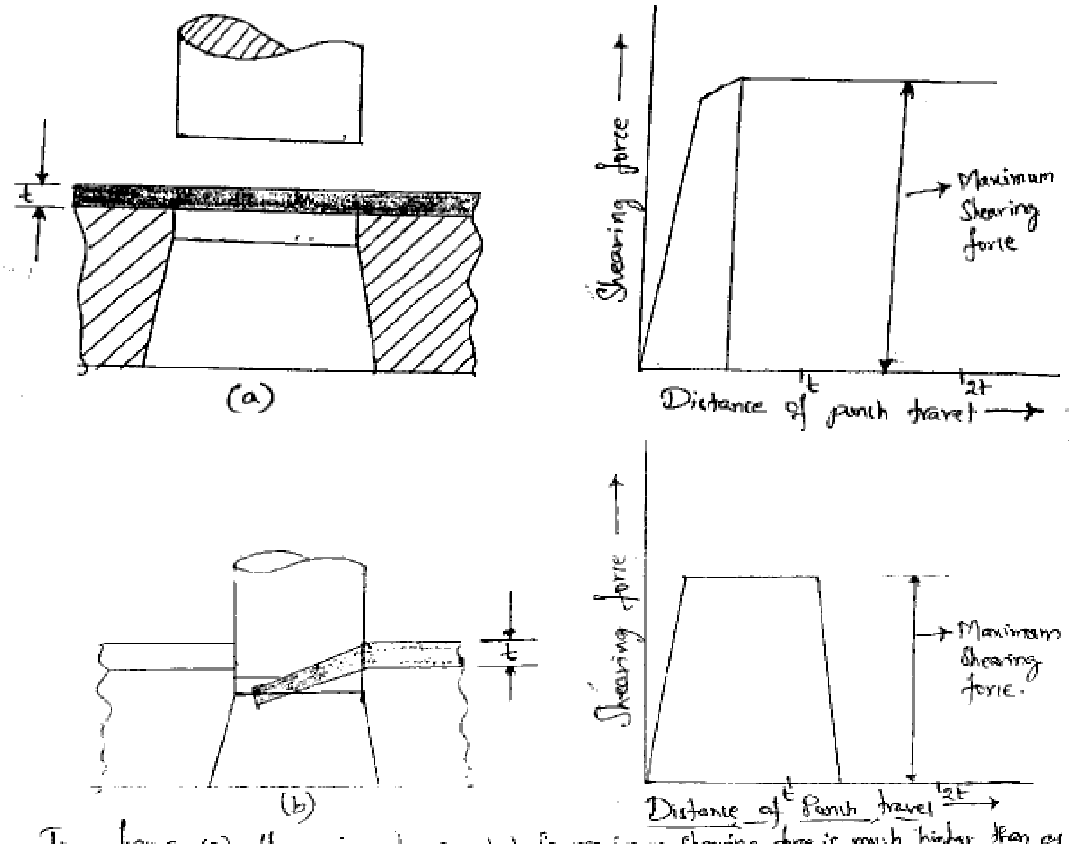
While discussing the shearing processes it was assumed that bottom of punch and top of die block are flat and lie in parallel planes. This process requires very high shearing force exerted over a very short time. It is usual practice to reduce cutting forces and to smooth out the shock of heavy loads by providing shear on either die or punch. The effect of providing shear is to distribute the cutting action over a period of time depending on the amount of shear provided. The following figure shows punching and blanking operations where shear is provided on punch and die respectively.



Use of Shear in Punching and Blanking (for blanking shear should be applied to die, for punching shear should be applied to punch.)

It may be noted that providing the shear only reduces the maximum force to be applied but not the total energy required in shearing the component. Shearing energy is equal to shearing force multiplied by penetration or distance necessary to effect the completer shearing. By providing shear on die or punch, maximum shearing force decreases and distance necessary to affect complete shearing increases. Thus we can say total energy required to shear provided on die and punch.

Effect of shear on shearing force is shown in below figure.



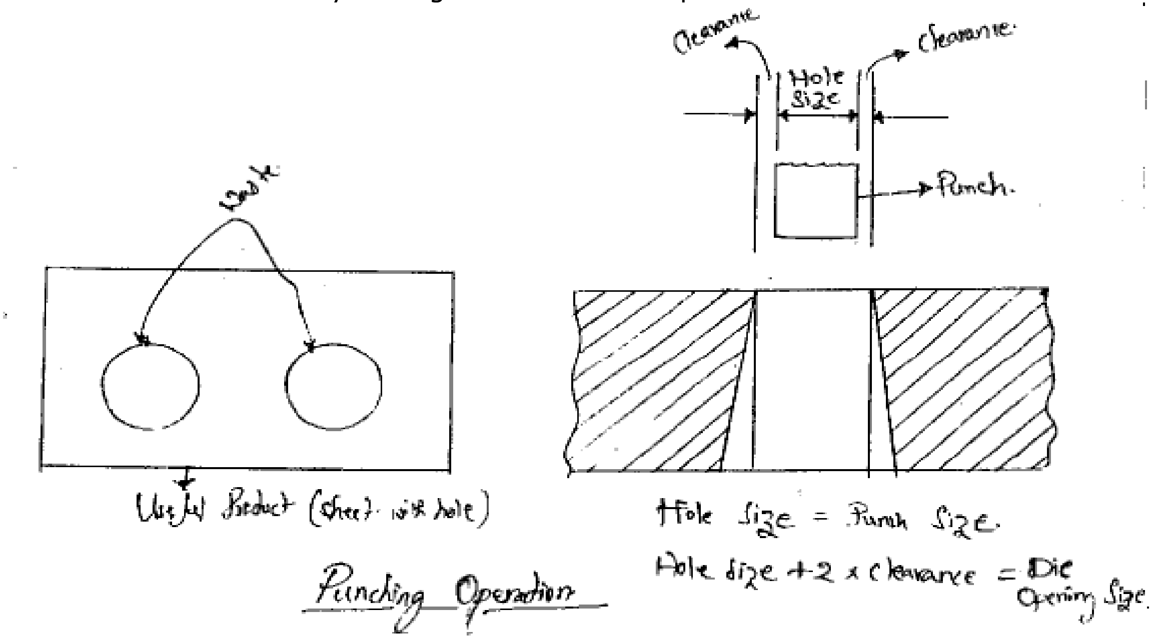
In figure (a) shear is not provided so maximum shearing force is much higher than as shown in fig (b). In fig (b) shear is applied so maximum shearing force is less than as shown in fig (a).

The provision of shear on the punch distorts the shape of blank and provision of shear on die would bend the stock with hole. So, in blanking operation to obtain the flat blank shear is provided on the die and for punching operation shear provided on the punch to obtain sheet with hole as flat.

Punching:

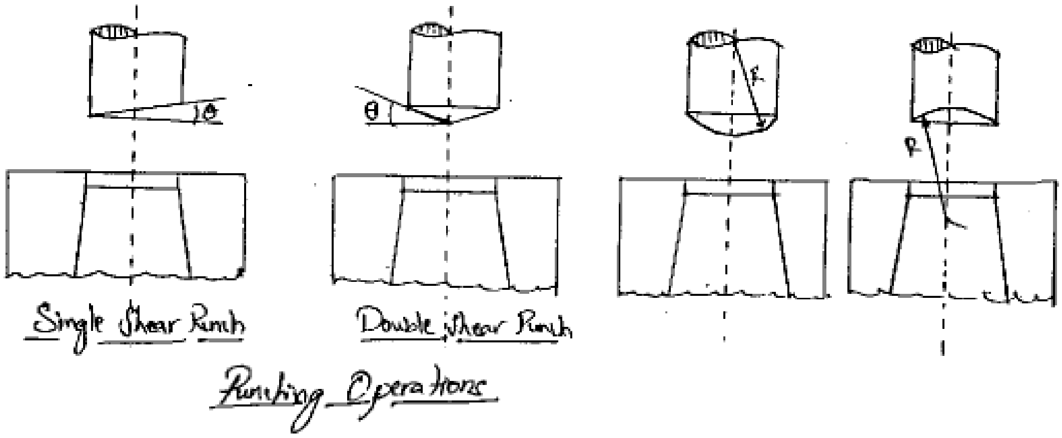
The punching is cutting operation by which various shaped holes are made in sheet metal strip. In punching operations sheet with the hole is desired product and material punched out is scrap. Normally punching operation is performed after blanking.

- The punch and die are made of a suitable hard and strong material, such as hardened high carbon steel, high chromium oil hardening steel or tungsten carbide.
- In punching operation the punch size equals the size of hole and die opening size is obtained by adding the clearance to punch size.



Piercing:

Piercing is a shearing process where a punch and die are used to create a hole in sheet metal or a plate. The process and machinery are usually the same as that used in blanking, except that the piece being punched out is scrap in the piercing process. There are many specialized types of piercing: lancing, perforating, notching, nibbling, shaving, cutoff, and dinking.



The amount of clearance between a punch and die for piercing is governed by the thickness and strength of the work-piece material being pierced. The punch-die clearance determines the load or pressure experienced at the cutting edge of the tool, commonly known as point pressure. Excessive point pressure can lead to accelerated wear and ultimately failure.

Burr height is typically used as an index to measure tool wear, because it is easy to measure during production.

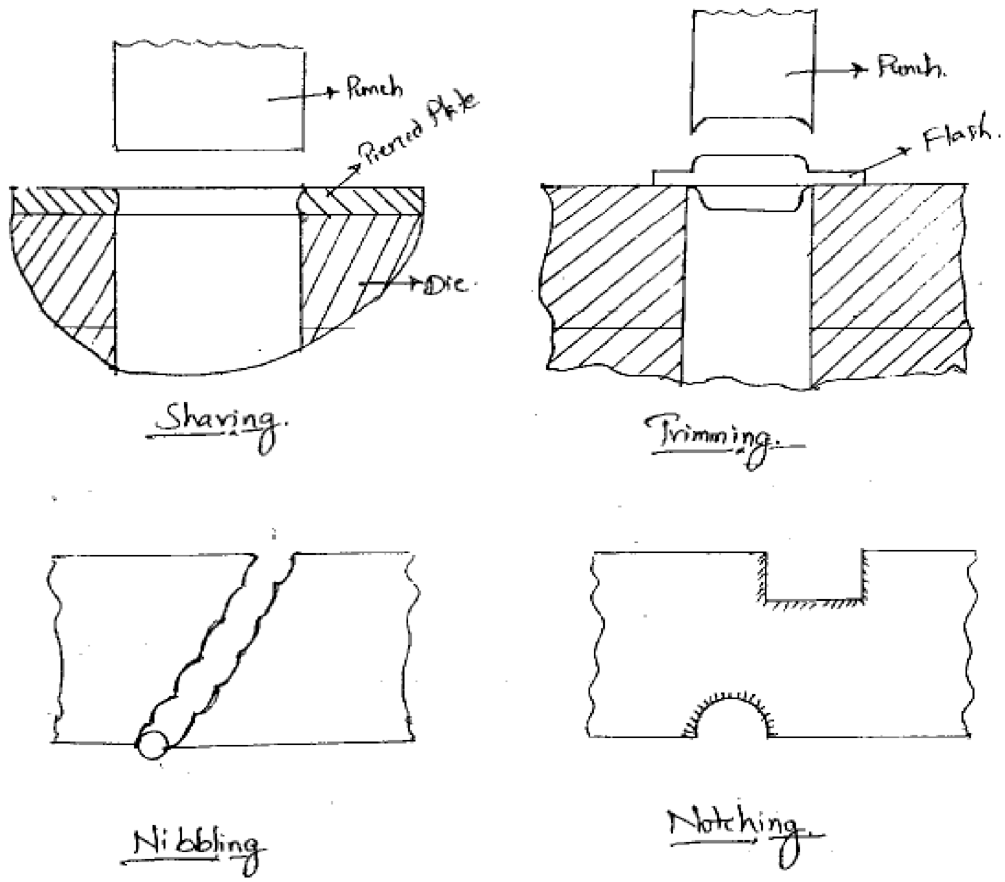
For simple piercing operations a pancake die is used.

Specialized types of piercing are,

- Lancing
- Perforating
- Notching
- Nibbling
- Shaving
- Cutoff

Shaving:

In blanking or piercing, the edge of blank or the hole is not perfectly clean because of burr generated in the shearing process. It is basically a finishing operation in which the small amount of material is sheared away from the edge of an already blanked or pierced part. Its primary use is to obtain greater dimensional accuracy. It is also used to produce a smoother edge. Because of only small amount of metal is removed the punches and dies must be made with very little clearance. Blanked parts such as small gears can be shared to produce dimensional accuracy within 0.025 mm.



Trimming:

In operations such as forging, die casting and drawing of sheet metals the small amount of excess metal gets spread out neat the parting line. This extra metal is called flash. The flash is to be trimmed before forging or casting is to be used. The dies used for this purpose are similar to blanking dies. The main difference is the type of presses used for trimming, which should normally have a large table. The figure shows trimming operation.

Nibbling:

In nibbling operation a specific contour is cut by producing a series of over lapping holes or notches as shown in figure. In this manner simple punches can be used to cut a complex shape from sheet metals. Nibbling is used when contour is long and separate punch is impractical and uneconomical. The punches used may be square, round or triangular depending upon the applications.

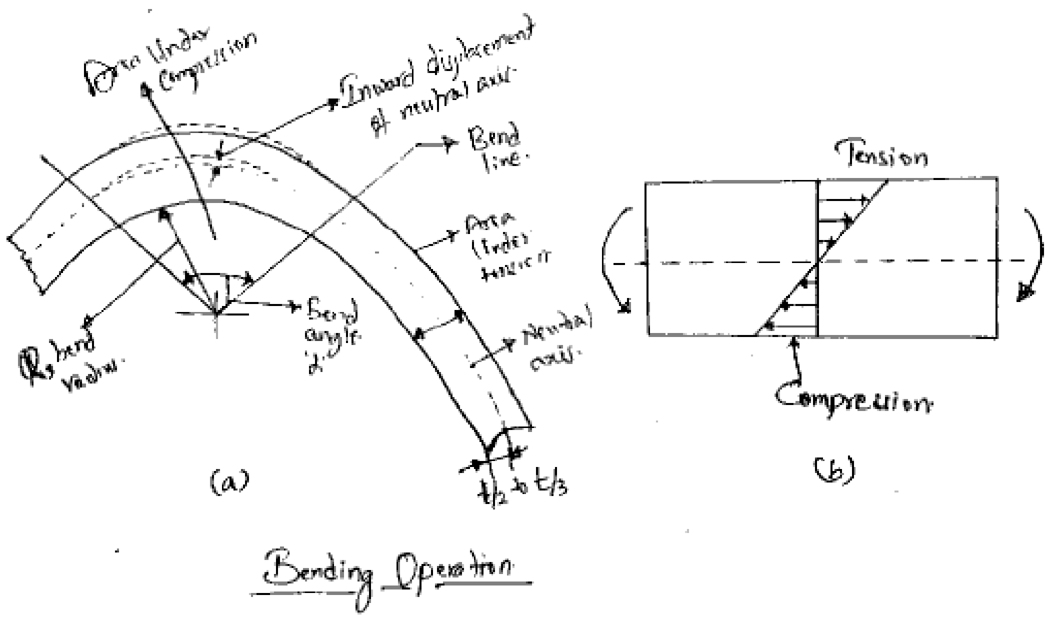
Notching:

Notching is essentially same as the piercing except that it removes small portion of metal along the edge of the stock.

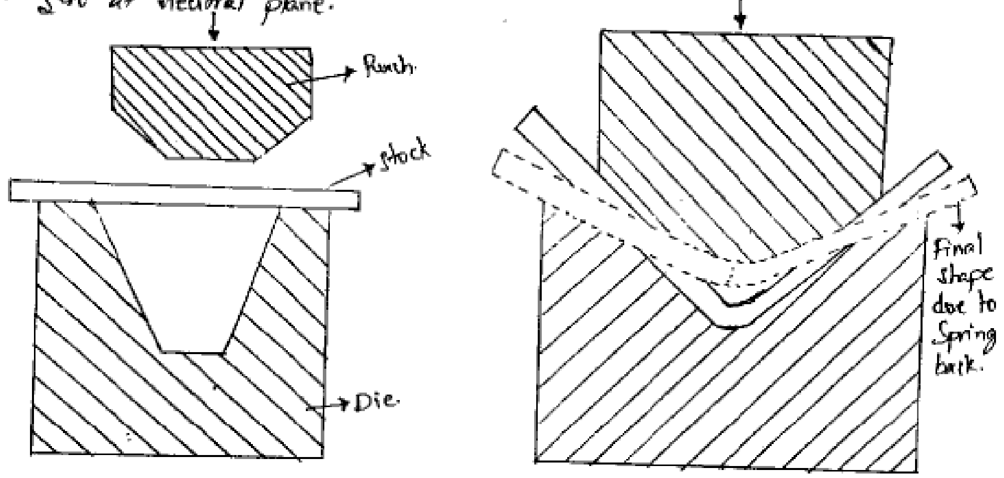
Bending:

Bending is the plastic deformation of metals about a linear axis with little or no change in surface area. The bending of flat sheet is shown in below figure. Here due to applied forces, metal on the outside is stretched while that on the inside is compressed. There is a plane in between which is neither stretched nor compressed. This plane is known as neutral plane. Neutral plane should be at the center when the material is elastically deformed. When the material is plastically deformed the neutral axis move downward towards compressed layer. Since materials oppose compression much better than tension. The thickness is slightly decreased.

In bending operations there is some elastic recovery after the punch is removed. This is known as spring back. Thus is metal is to bent at specific angel the metal must be slightly over bent to compensate for the unbending action of spring back. Bending operation is performed while manufacturing many components such as trays, boxes, brackets, clips etc…



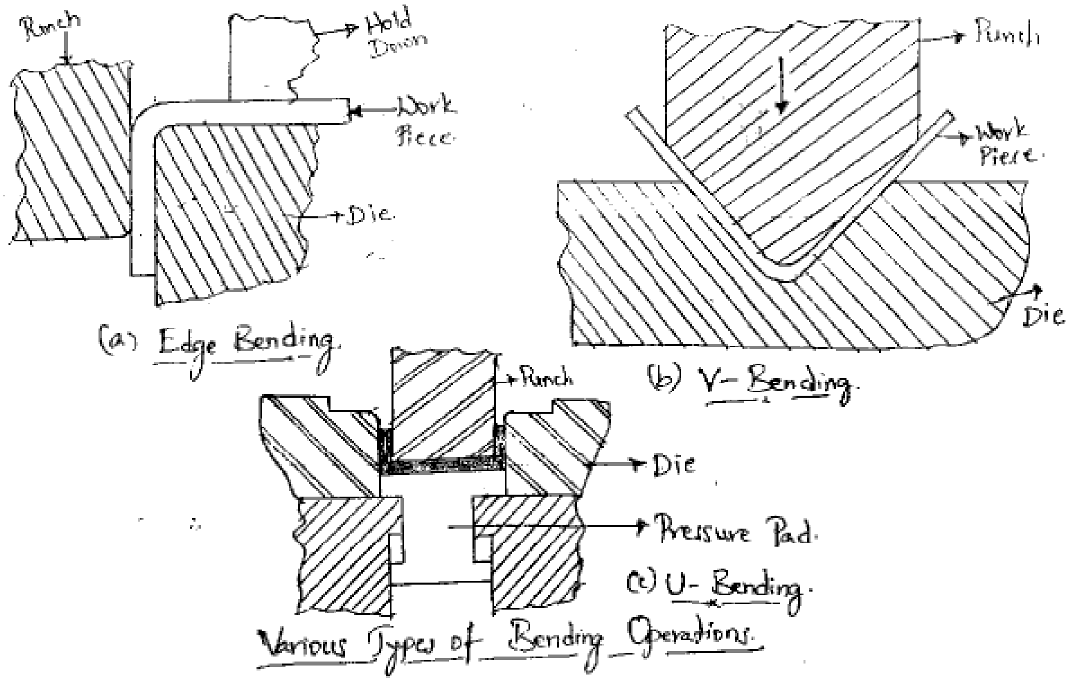
The figure (a) shows a simple case of bending and inward displacement of neutral axis in bending. Figure (b) illustrates that stresses on the outer most sides are maximum and zero at neutral plane.



Spring Back in Bending Operation

Different types of bending methods are shown in below figure. The first one is edge bending which is used for simple 90° bend only. Here the work piece is held firmly to the die with hold down and punch bends the extended portion of metallic blank. Here the work piece behaves a cantilever beam. V-bending and U-bending is shown is second figure. The punch and die often form a 90° internal angle between the faces of the metal.

Bending operation is closely related to forming operation. Bending is sometimes called forming operation, when multiple bends are made with single die. If the axes of deformation are not linear or are independent, the process becomes drawing and or stretching.



Various Types of Bending Operations.

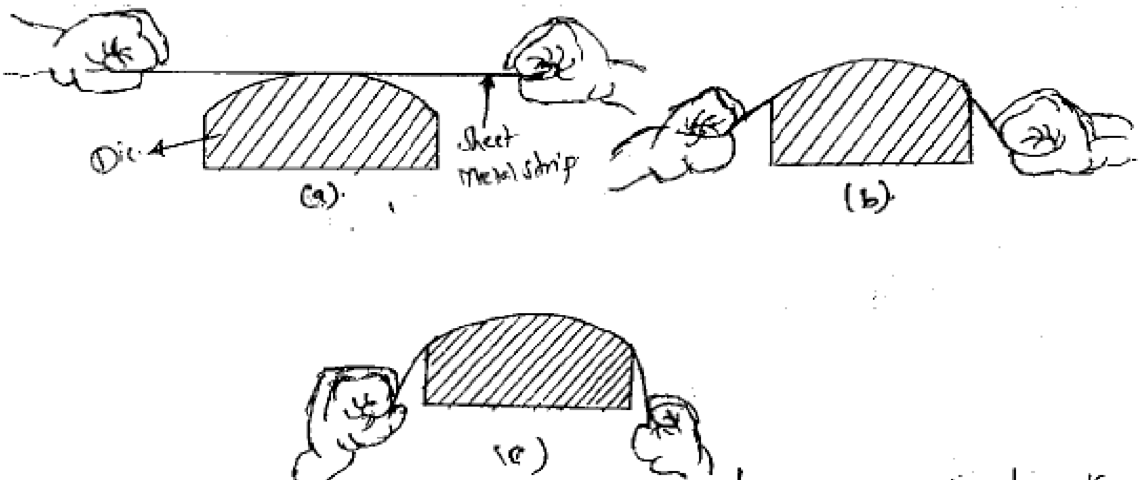
Forming:

Forming is the operation which reproduces flat stock into the shape of punch and dies with little or no plastic flow of the metal. An example is a punch and dies designed to form a flat strip of steel into a U – shape.

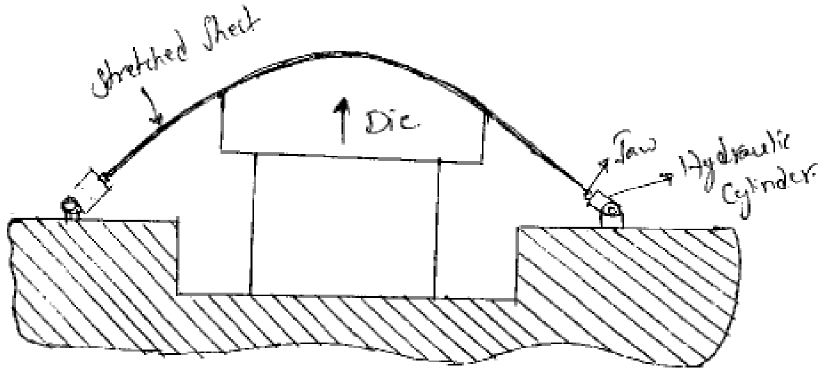
Stretch Forming

Stretch forming is an attractive way of producing the large sheet metal parts in limited or low quantities. In this process the sheet of metal is gripped by two or more sets of jaws that stretch it and wrap it around a single form die block. This process of simultaneously stretching and bending is called stretch bending.

In stretch forming most of the deformation is induced by the tensile stretching, therefore forces on the die are far less than those normally present in bending or forming because forces are so low that the dies can often be made of wood, low melting point metal or even plastic.



Various steps to illustrate the process of Stretch forming. It is also shown the raw metal is subjected to stretching and bending in stretch forming.



Stretch Forming

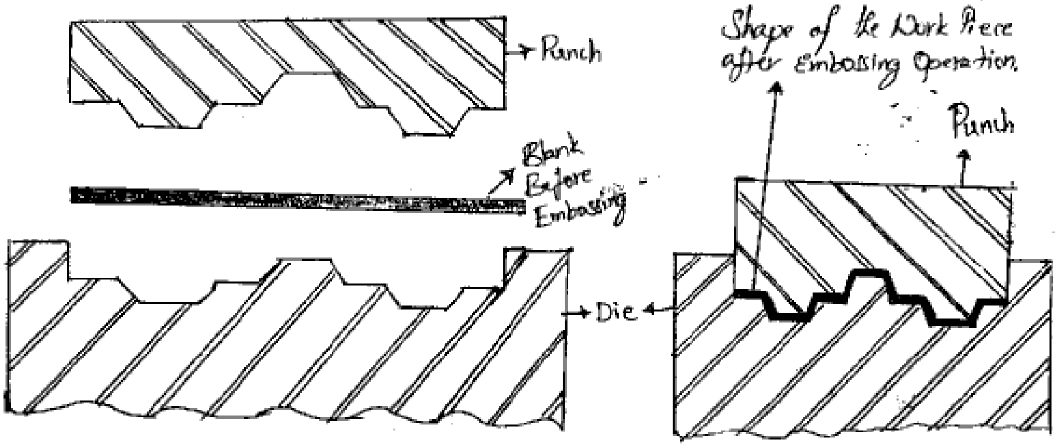
- As in the process deformation is carried out in plastic region there is very little spring back and work piece closely conforms to the shape of tool.
- In stretch forming we can have component either single or double curved surfaces. The sheet should have uniform thickness other wise the thinner portions are likely to be over stretched. Also if the sheer is having any holes before the stretch forming they are likely to be enlarged.
- Stretch forming is quite popular in the air craft industry and frequently used to form aluminium and stainless steel into wing tips, scoops and other large panels.

- Sometimes mating male and female dies are used to shape the metal while it is being stretched. This process is known as stretch draw forming.

Embossing:

Embossing is the operation in which projected or raised figures are made on sheet metals with corresponding relief on the other side. It basically involves drawing and bending operation. There may be the negligible change in the thickness of the metal.

- The die set consists of punch and die with required contours which are desired on the final product. The clearance between punch and die at meeting is same as the thickness of required product.
- Embossing is used for providing rigidity to sheet metals and for decorative sheet work used in houses and religious places.



Drawing:

It is also known as cold drawing refers to two different operations.

(a) If the starting material is sheet metal than the operation is sheet metal drawing.
(b) If the starting material is wire, rod or tube then the operation is wire drawing rod drawing or tube drawing respectively.

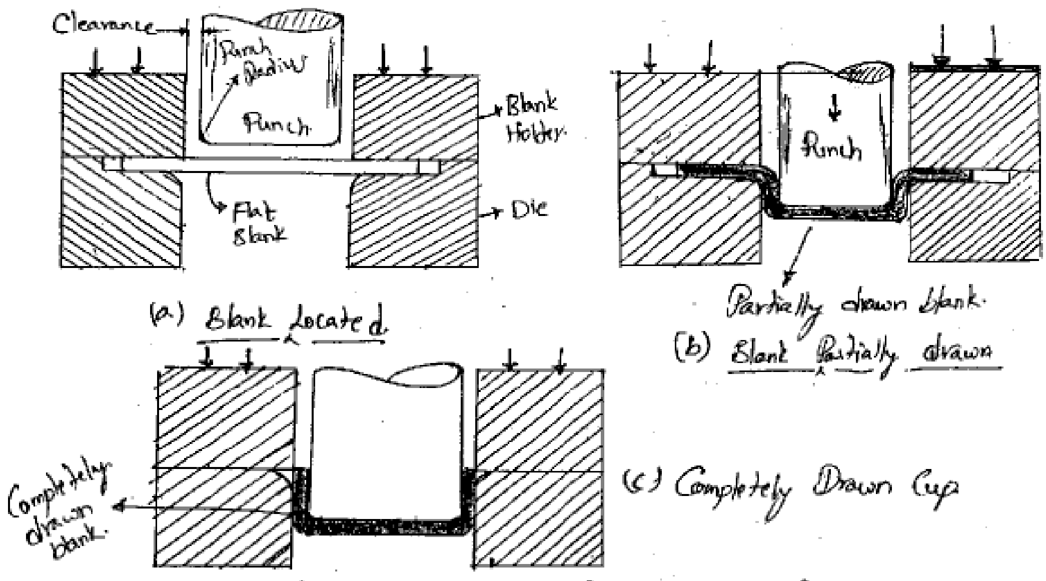
(a) Sheet Metal Drawing:

Sheet metal drawing is defined as process for making cup shaped articles from flat sheet metal blanks. Common examples of such components are dishes, trays, brake drums, cylindrical container etc… Sheet metal drawing operation is shown in below figure.

The set up is similar to that used in blanking except that punch and die are provided with necessary rounding at the corner. The rounding is provided to allow the smooth flow of metal during drawing. The blank is first placed and located above the die. The blank holder comes down properly holds the edges of the blank. After this punch moves downwards to force, the blank to take the shape of cup formed by the end of the punch. The punch and blank holder then returns upward to complete the cycle.

- The punch and die radius should be equal and sufficient large (about 5 times thickness of metal). Large punch radius prevents fracture of metal near the end of punch where tensile forces are maximum. Large die radius prevents tearings of metal as it flows over the edge of the die. The radius should not be too large otherwise wrinkle may form.

- The depth of draw in sheet metal drawing may be shallow, moderate or deep. If the depth of formed cup is less than half its diameter the process is called shallow drawing. If the depth of formed cup exceeds the diameter, it is known as deep drawing. Bottle caps and automobile panes are the examples of drawing process.

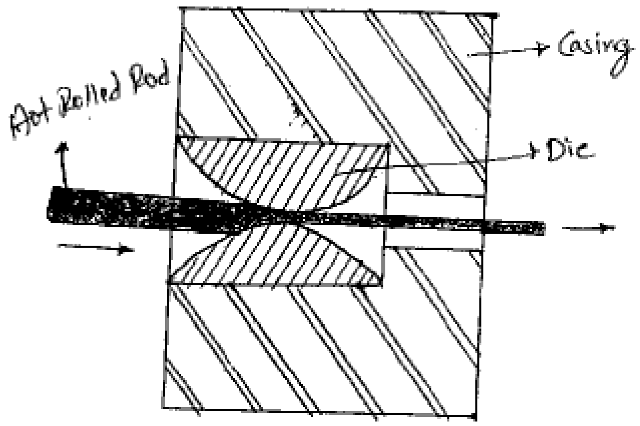


Cup Drawing (Shallow Drawing)

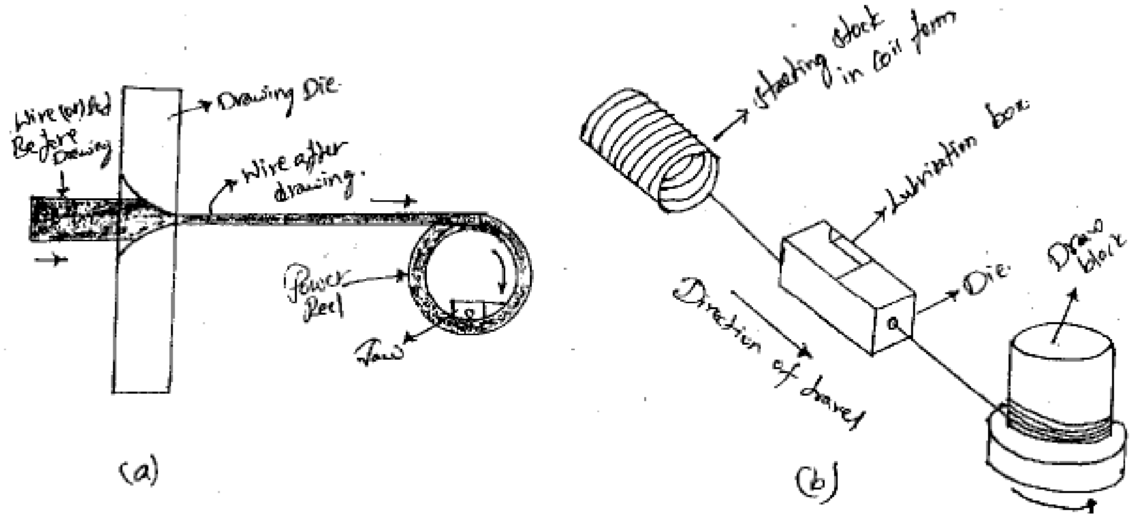
(b) Wire Drawing:

Wire may be defined as metal in form of thread or slender rod which id flexible. Wire drawing process is to obtain wires from rods of bigger diameter through die. Rods are the bars with circular cross section. Wire drawing is always a cold working process.

The below first figure shows wore drawing die and second figure shows wire drawing machine. The opening in the die is generally conical. The end of the wire to be drawn is made in to a point shape and inserted through the die opening. This end is then gripped properly and pulled sufficiently by suitable means so that this end can be attached to power reel. From them on, power reel rotates at proper speed and pulls the entire piece through die.



Wire Drawing Process



Before the wire is drawn stock needs to be prepared for wire drawing. The four major aspects of stock preparation for wire drawing are as follows:

1. **Annealing:** The wire should be annealed properly as the material looses its ductility during wire drawing process and when it is to be repeatedly drawn to bring it to the final size, intermediate annealing is required to restore the ductility.

2. **Preparation of conical end:** As the wire is to go through conical portion of die and then pulled out through the exit by gripper. In this process there is no force applied for pushing the wire into die from entrance side. To make an easy entry of wire into die the end of the stock is made pointed by means of simple hammering or by rotary swaging.

3. **Cleaning:** The wire should be cleaned properly as it flows through the die. Cleaning is essentially done to remove any scale and rust present on the surface which may severely affect the die. Cleaning is normally done by acid pickling.

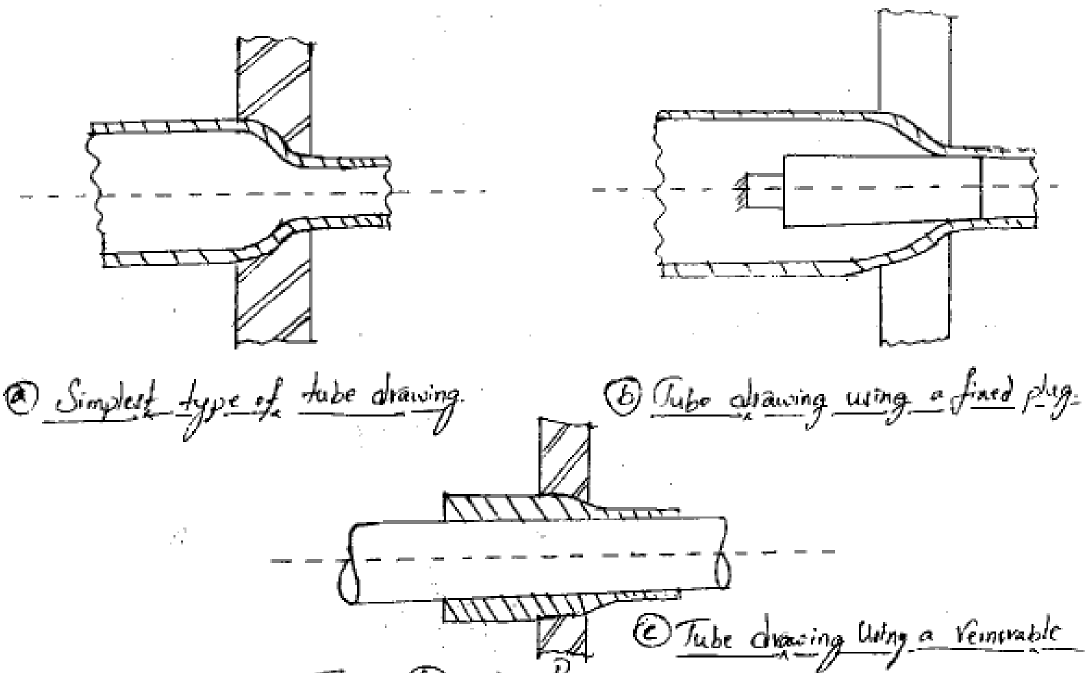
4. **Lubrication:** The pressure acting at the interface of metal and die is quire high and, therefore lubrication of die is a serious problem. Two methods of lubrication are widely employed. In one method wire surface is cleaned, coated with lime and thoroughly dried. Before entering the die lubricant such as grease or soap is applied to surface of wire or rod. Second method is used for very thin wires. In this case electrolytic coating of copper is used to reduce friction.

   The material of wire drawing die are generally chilled cast iron, hardened alloy steel, tungsten carbide of diamond. Tungsten carbide die are preferred because of their long life.

Tube Drawing:

Tube drawing is also similar to the other drawing processes. There are three basic types of tube drawing processes as shown in below three figures.

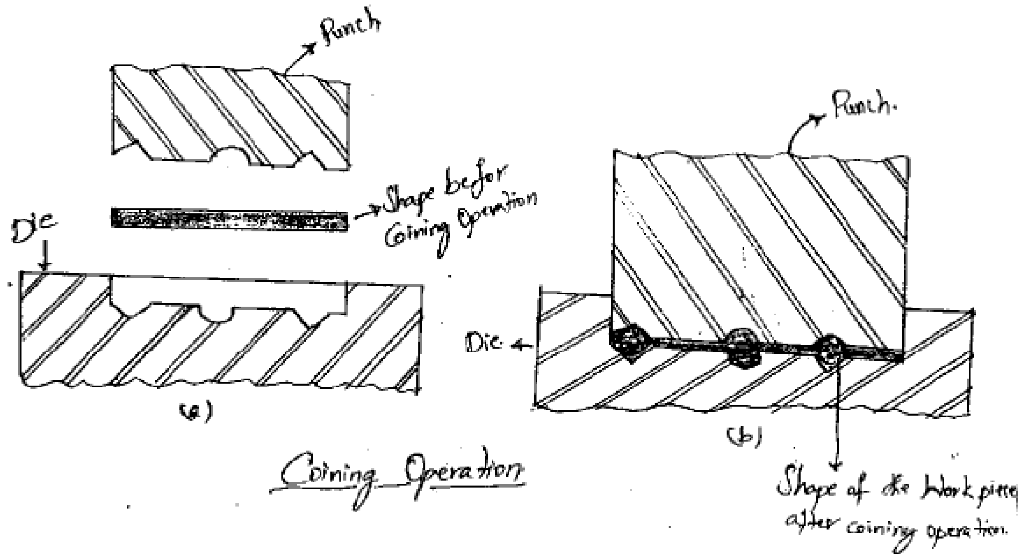
The first figure indicates the simplest form of tube drawing process. In this process, no internal mandrel is used hence if is called sinking process. The technique shown in second figure reduces the tube diameter and controls its thickness. However, the imitation is length of the tube by length of the mandrel. To over come this problem, moving mandrel as shown in third figure is used. The tubes are also first pointed and then entered through the die and on the other side of the die; this end is gripped in tongs, which is connected to the draw bench. There may be more than one pass required to get the final size. The reduction in one pass is about 40 percent. The metal is annealed after every pass in order to remove the effect of strain hardening. Hot drawn tubes are also cold drawn to provide good surface finish, better dimensional accuracy and improved physical properties.



Tube Drawing Process

Coining:

Coining is basically a cold forging operation. The only difference is that here the flow of metal occurs only at top layers and not at the entire volume as in case of cold forming.



Coining Operation

The process is used to produce coins, meals and similar products where exact size and fine details are required. The coining die consists of punch and dies which are engraved with necessary details required on the both sides of final product. A blank is kept on the die and squeezed by it. The pressure required in coining is quite high as very fine details are required in coining. For example, a pressure of 240,00 psi may be required to make a nickel coin of 50 paise.

Spinning:

Spinning is the process used for making cup shaped parts having symmetrical shapes. In this process a blank is rotated, fixed against the forms block and then gradually force is applied on blank so that, blank takes the shape of form block.

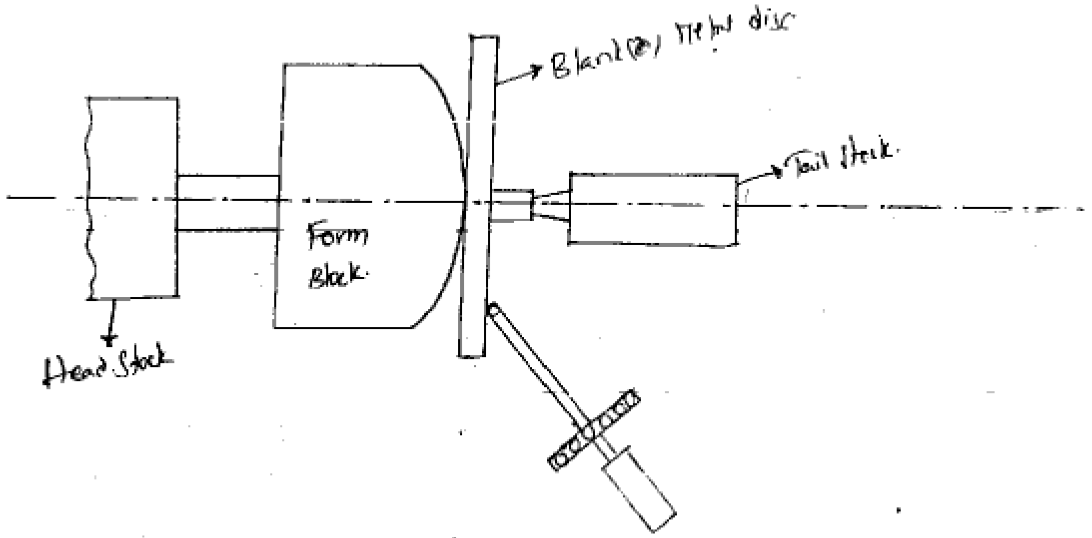
The spinning process may be carried out on machine similar to a lathe machine. A circular blank properly centered with lathe axis is held against the chuck by the pressure of follower attached to tails stock. The form block, which has the shape of desired part, is fixed to the head stock of lathe machine. The tool used in spinning is simple round ended wooden or metal tool or small roller. As the blank and form block are made to rotate, the tool is pressed and moved gradually on the blank so that blank take the shape of form block.

Spinning Lathe

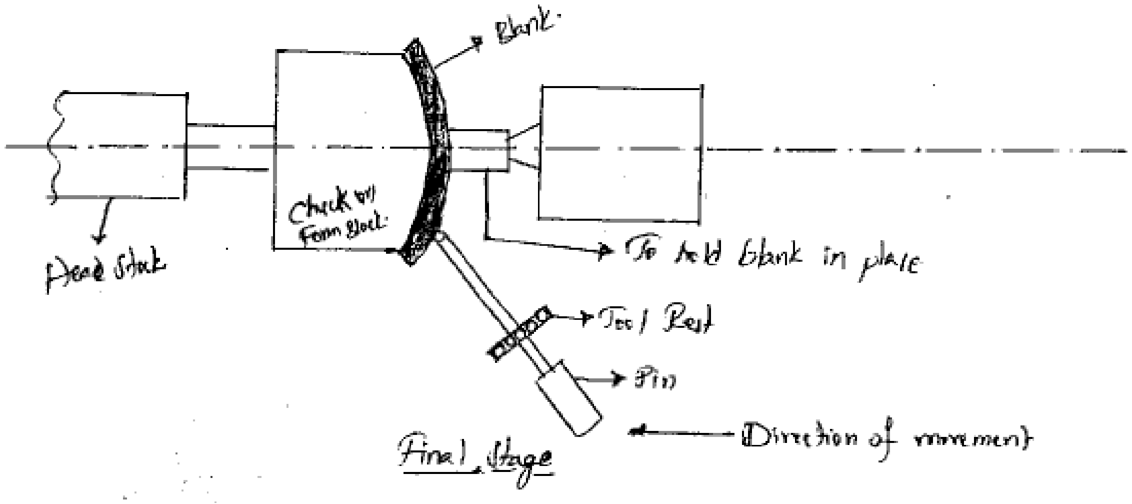
The spinning lathe consists of,

1. Bed
2. Head Stock
3. Form
4. Tail Stock

The bed supports head stock, tail stock and other accessories. The form block is fixed in the lathe spindle and turns with it. The work piece is bent over the form block to take its shape by applying pressure by means of tool. The follower supports the work piece. Steps in spinning are shown in below figure.



Initial Stage



Spinning Operation

Types of Spinning Processes:
The Spinning process is classified in two types i.e., hot-spinning and cold-spinning, depending upon whether the blank or work piece has been heated before spinning or not.

(i) Hot Spinning:
In hot spinning, the metal blank is heated to forging temperature and then forming it into the desired shape.

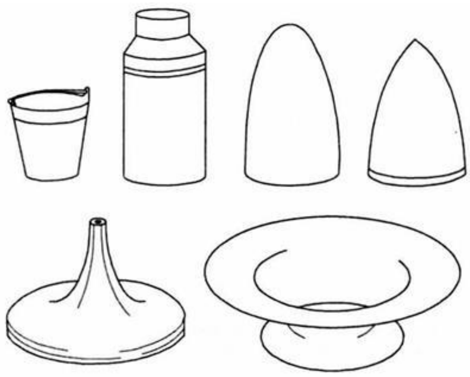
A blunt pressing tool is used which contacts the surface of the rotating part and causes the flow of metal over the form mandrel. This method is generally used for thicker plates and sheets, which do not plastically de-formed at room temperature by pressing tool.

In order to avoid wrinkling at the outer edge a back-up support (hard wood bar) opposite to the tool is used, when working with relatively thin sheets. Hot spinning produces parts such as heads for pressure vessels, refinery equipment's and large tanks.

(ii) Cold Spinning:
Cold spinning process is similar to hot spinning except that the metal blank is worked at room temperature. This method is generally best suited for thin plates and sheets of aluminum and other soft metals.

Cold spinning produces parts such as light reflectors, cooking utensils, liquid containers, radial engine cowling, domestic use hollow parts etc.

Products of Spinning:

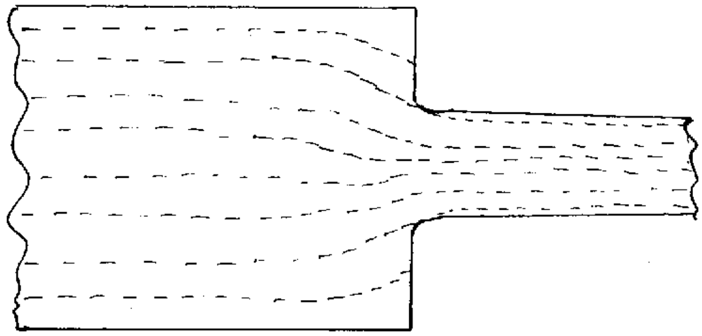


UNIT – 4: Extrusion and Forging Processes

- **Extrusion**
- **Range of Extrusion Products**
- **Advantages**
- **Disadvantages**
- **Classification of Extrusion Process**
- **Hot Extrusion Process**
- **Cold Extrusion Process**
- **Forging**
- **Forge Ability of Metal And Alloys**
- **Forgeable Materials**
- **Forging Temperatures**
- **Hand Forging Tools and Equipment Used In Smithy:**
- **Basic Forging Operations**
- **Forging Processes & Classification**
- **Die**
- **Open Die Forging**
- **Impression Die Forging**
- **Roll Forging**
- **Rotary Forging or Swaging**
- **Fibrous Structure of Forgings**
- **Advantages of Forging**
- **Limitations of Forging**
- **Defects in Forging Parts**

Extrusion:

Extrusion is the process of confining the metal in closed cavity and then forcing it to flow from one opening (die), so that metal will take the shape of opening. The operation of extrusion is similar to the squeezing of tooth paste out of toothpaste. The paste inside the tooth paste has no shape, when the tooth paste tube is squeezed the paste flows out of the circular opening taking the shape of the opening.



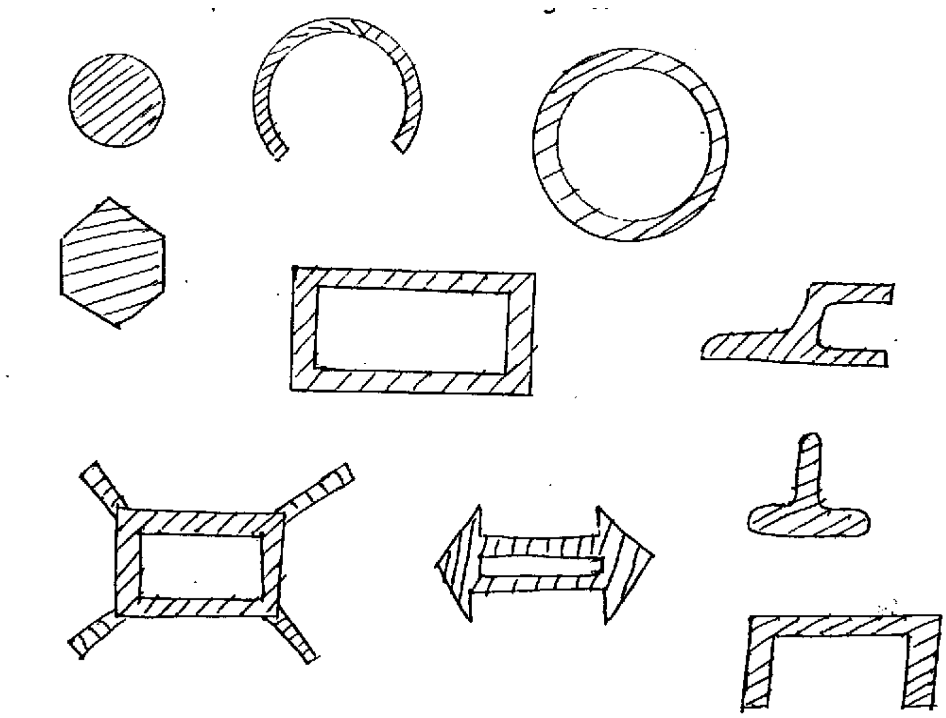
Metal flow in Direct Extrusion.

Range of Extrusion Products:

Extrusion process is used to manufacture products like;

(i) Rods
(ii) Tubes
(iii) A variety of circular, square, rectangular, hexagonal and other shapes both in solid or hollow form.
(iv) Channels like I and T and other sections.

Some of the extruded shapes are shown in below figure:



Advantages of the extrusion process are as follows:

1. Extrusion is a single pass process unlike rolling.
2. Dies are easy to manufacture.
3. Variety of shapes of high strength, good accuracy and surface finish can be obtained.
4. High production rate with relatively low die cost.
5. Complicated cross – sectional shapes which are not possible to achieve by rolling can be achieved by extrusion.
6. Larger deformation can be achieved by this process than other processes except casting.
7. Dies can be easily replaced and removed with no loss of time.

Disadvantages:

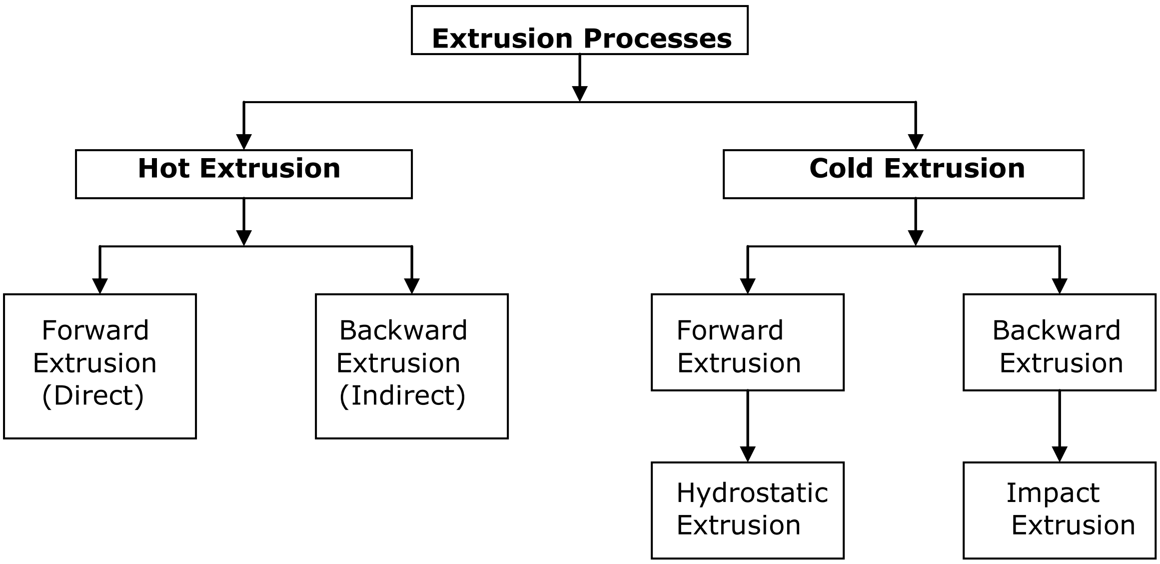
1. Tools are expensive.
2. Metal blank should be free from internal or external defects.

Classification of Extrusion Processes:

The process of extrusion consists of forcing a heated billet inside a chamber through a small opening called die under high pressure. The high pressure is obtained by hydraulic press or mechanical press. In its cross section, the extruded metal acquires the contour and dimensions of the die opening. Extrusion is more widely used in fabricating non-ferrous metals and their alloys.

The Extrusion process can be classified as:

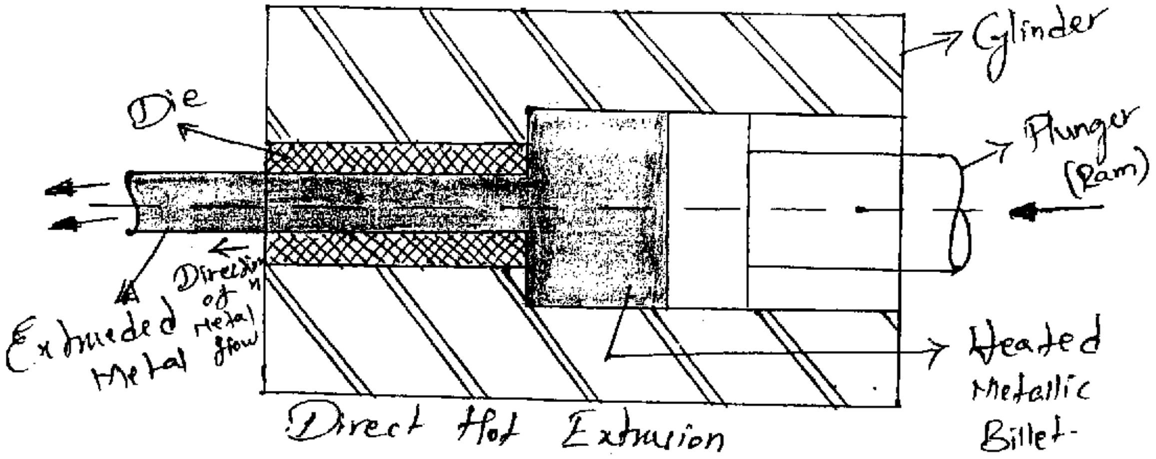
1. Hot extrusion process
2. Cold Extrusion Process



Hot Extrusion Process:

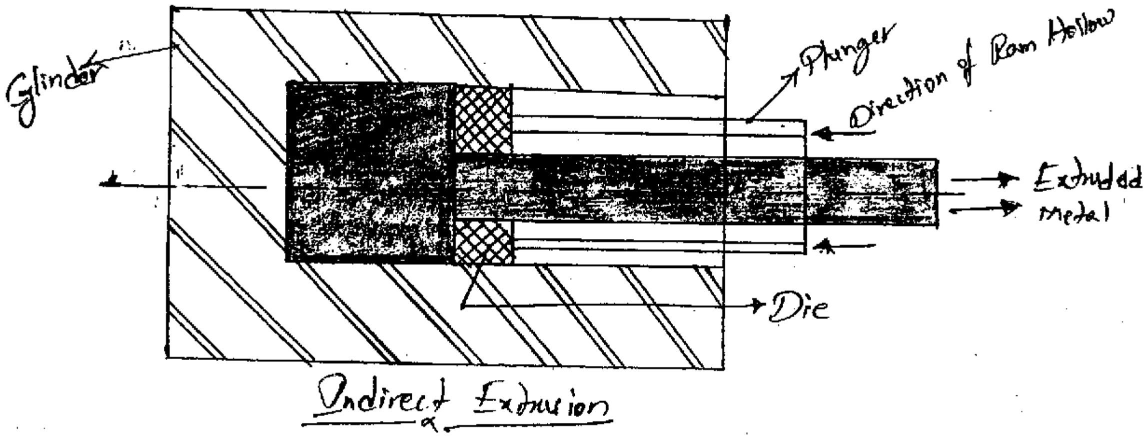
(i) Direct Hot Extrusion (Forward extrusion)

This is the most widely used method. A hot billet is placed in the container and the forced through the die with the help of pressure by a hydraulic driven ram. The extruded metal comes out of the die opening. In this process, the flow of metal through the die is in the same direction as the movement of the ram. The length of the extruded part will depend on the size of the billet and cross section of the die.



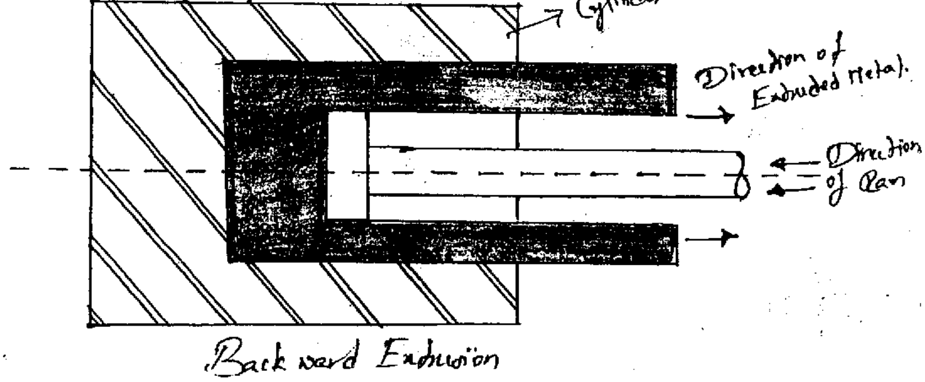
(ii) Indirect Hot Extrusion:

For this type of extrusion, the ram used is hollow and the die is mounted over the bore of the ream. In this process, the billet remains stationary, while the die is pushed into the billet by hollow ram. The metal flows in the direction opposite to the movement of the ram. Indirect extrusion does not require as much force as direct extrusion because no force is required to move the billet inside the chamber.



(iii) Backward Extrusion:

This is another indirect extrusion method used in manufacturing hollow sections as shown in figure. In direct and indirect extrusion methods the ram is of the same diameter as the bore of the container, where as in backward extrusion the ram is smaller in diameter than the container. In this process, the metal is extruded through the gap between the ram as the container.



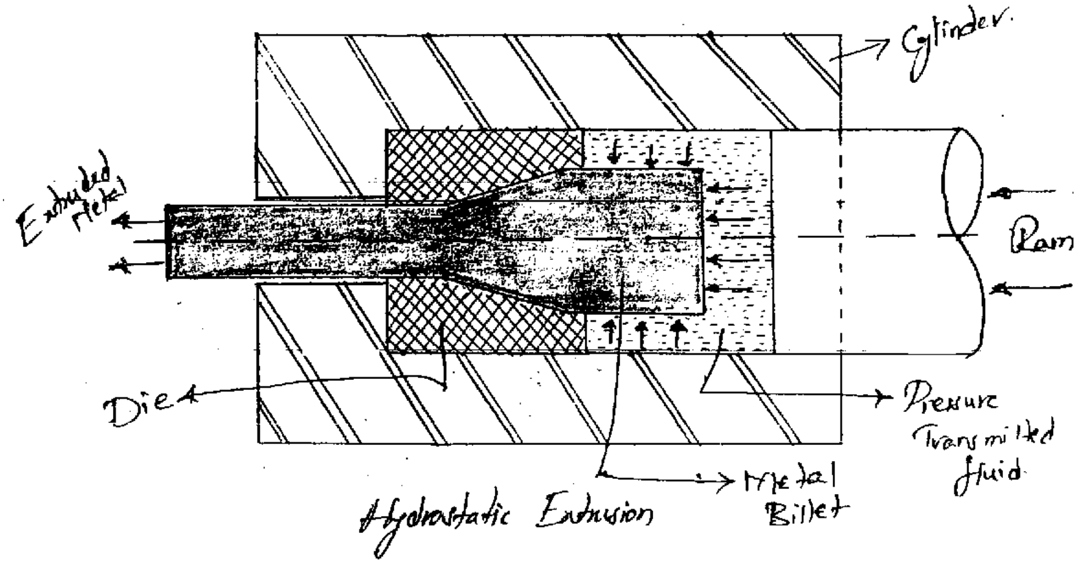
Cold Extrusion Process:

(i) Forward Cold Extrusion:

The forward cold extrusion is similar to forward hot extrusion except that temperature is comparatively lower and extrusion pressures are higher than got extrusion. It is usually used for simple shapes. The cold extruded products have better surface finish and improved mechanical properties. The common applications of cold extrusion are aluminium brackets, tubes, shock-absorber cylinders etc… Now a day's cold extrusion has also been used for forming mild steel parts often in combination with cold forging.

Hydrostatic Extrusion:

It is another extrusion process which makes possible to cold extrude many difficult to form materials such as high strength super alloys, molybdenum etc… Here instead of applying the load directly by ram, a liquid medium us used. The presence of liquid inside the container eliminates the need of lubricant and also force transmitted is uniform from all sides through out the deformation zone. Because of this highly brittle materials such as grey cast iron can also be extruded. Applications include extrusion of reactor fuel rods, making wire of less ductile materials.



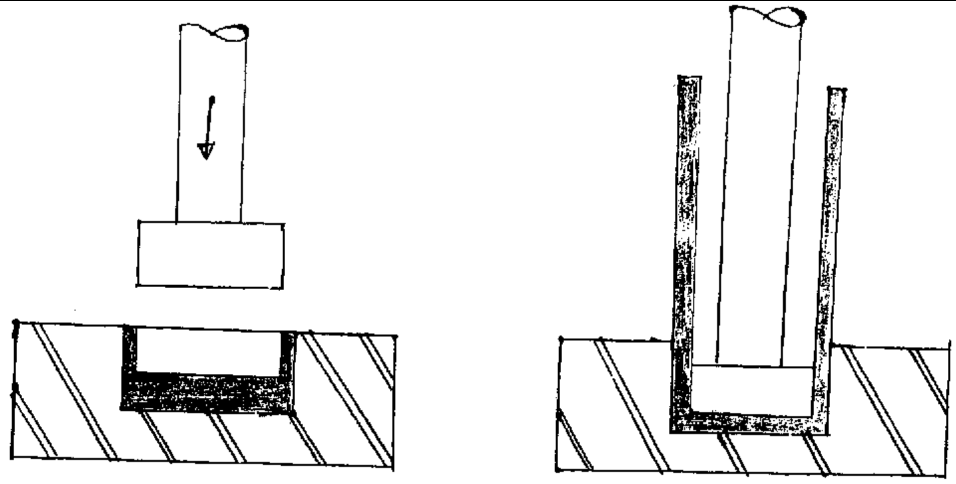
(ii) Backward Cold Extrusion (or)Impact Extrusion:

The backward cold extrusion is called impact extrusion. This process involves striking a cold slug of soft metal (like aluminium) which is held in a shallow die cavity with a moving punch. The metals then extruded through the gap between the punch and die opposite to the punch movement. The height of the sidewalls is controlled by the amount of metal in the slag. Various items of daily use such as tubes for shaving cream, toothpaste and paints are made by impact extrusion.

There are three types of impact extrusion processes:

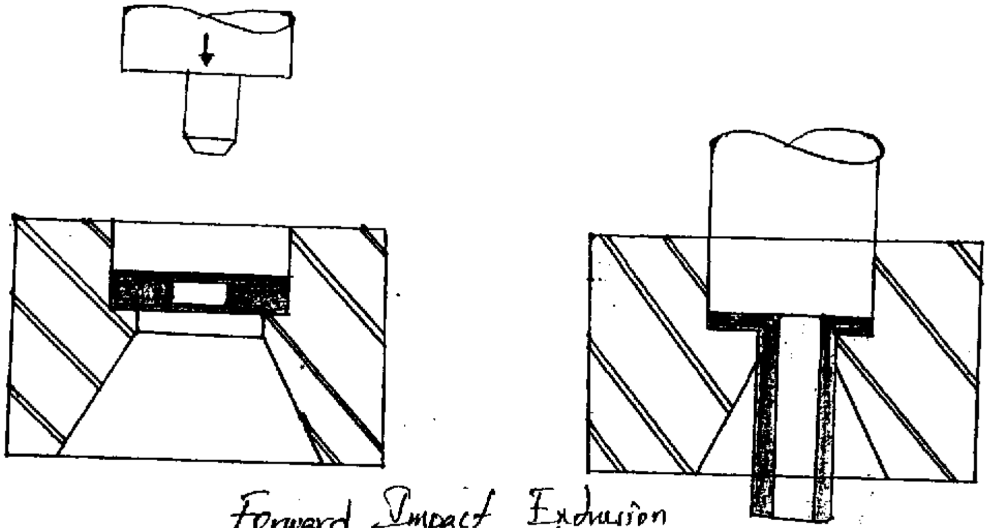
(a) Reverse impact extrusion
(b) Forward impact extrusion
(c) Combination impact extrusion

(a) Reverse Impact Extrusion: The following figure indicates the process of reverse impact extrusion. In this process, the metal flows in reverse direction of the plunger. It is used for making hollow parts with forged bases and extruded walls. The flowing metal is guided only initially, thereafter if goes by its own inertia.



Reverse Impact Extrusion

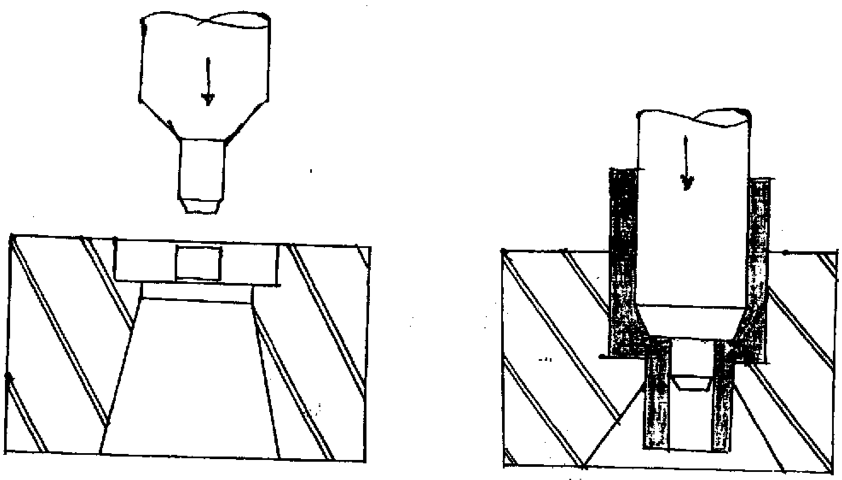
(b) Forward Impact Extrusion: The process of forward impact extrusion is shown in below figure. It is mainly used for making hollow or semi hollow products with heavy flanges.



Forward Impact Extrusion

(d) Combination Impact Extrusion: Complex shapes can be produced by a combination of the two preceding procedures, which are performed simultaneously in the same single stroke as shown in below figure.

(e)



Combination Impact Extrusion

Forging:

Forging is the oldest metal working process known to mankind. In this process material is squeezed between two or more dies to deform its shape and size in such a way that required final shape is obtained.

Forging is the operation where the metal is heated and then a force (impact type or squeeze type) is applied to manipulate the metal in such a way that the required final shape is obtained.

Forging always considered as hot working unless specified. Forging enhances the mechanical properties of metals and improves the grain flow, which in turn increases the strength and toughness of the forged component.

Forge ability of Metal and Alloys:

It is important to know the deformation behaviour of the metal to be forged with regard to the resistance to deformation and any anticipated adverse effects such as cracking. Hence, forgeability can be defined as the tolerance of a metal or alloy for deformation without failure. It can be evaluated on the basis of the following tests:

(a) Hot twist test
(b) Upset test
(c) Hot-impact tensile test

(a) Hot Twist Test: In this test, hot bar is twisted and count the number of twists until failure. A large number of twists before failure indicate better forgeability.

(b) Upset Test: This test is widely used in the forging industry. In this test, a number of cylindrical billets are upset-forged to various thicknesses. The limit for upset forging without failure or cracking is considered a measure of forgeability.

(c) Hot Impact Tensile Test: A conventional impact testing machine fitted with a tension test attachment is used. The impact tensile strength is taken as measure of forgeability.

Forgeable Materials:

In general, the selection of a forging material is made on the basis of certain desirable mechanical properties inherent in the composition and for those which can be developed by forging such as strength, resistance to fatigue, good machining characteristics, durability etc…

Following is a list indicating the relative forgeability of some alloys in a descending order i.e., alloys with better forgeability are mentioned first;

1. Aluminium alloys
2. Magnesium alloys
3. Copper alloys
4. Plain carbon steels
5. Low – alloy steels
6. Martensitic stainless steels
7. Austenitic stainless steels
8. Nickel alloys
9. Titanium alloys
10. Tantalum alloys
11. Molybdenum alloys
12. Tungsten alloys

Forging Temperatures:

For forging, the metal work piece is heated to a proper temperature to attain plastic properties before deformation which is essential for satisfactory forging. Excessive temperature may result in burning of the metal. Insufficient temperatures will not induce sufficient plasticity in the metal so that it is difficult to shape by hammering. Like wise finishing temperatures is also important to posses a fine grained structure. The temperature ranges for forging some common metals are given below:

Metal / Alloy	Forging Temperature °C	
	Starting	Finishing
Mild Steel	1300	800
Wrought Iron	1275	900
Medium Carbon Steel	1250	750
High Carbon Steel	1150	825
Copper, brass and bronze	950	600
Aluminium and magnesium alloys	500	350

Forging Temperatures

Hand Forging Tools and Equipment used in Smithy:

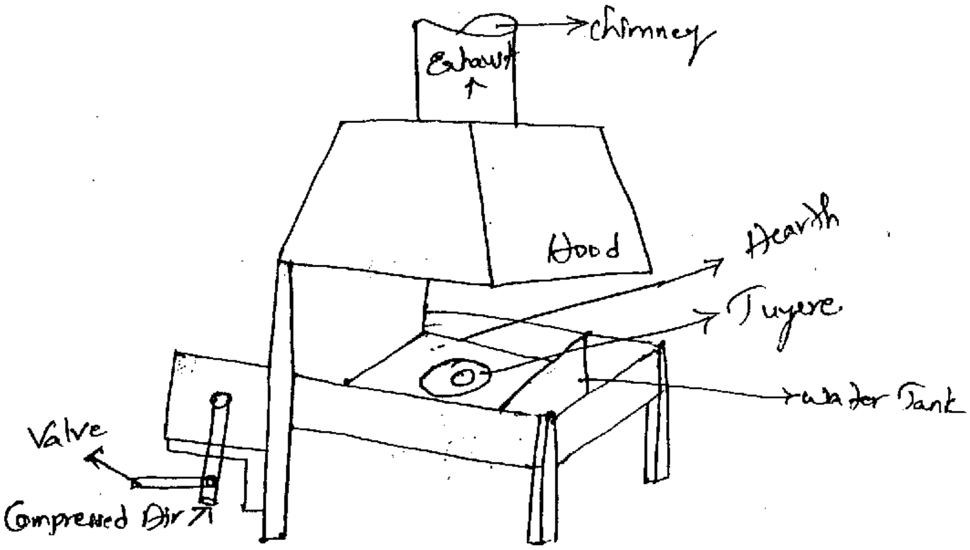
In order to carry out forging with hand, various tools are required:

(1) Black Smiths Forge:

The smith's forge or hearth is made up of cast iron or cast steel. It has four legs as shown in figure. The hearth can also be made of masonary construction but have a disadvantage that they are not portable.

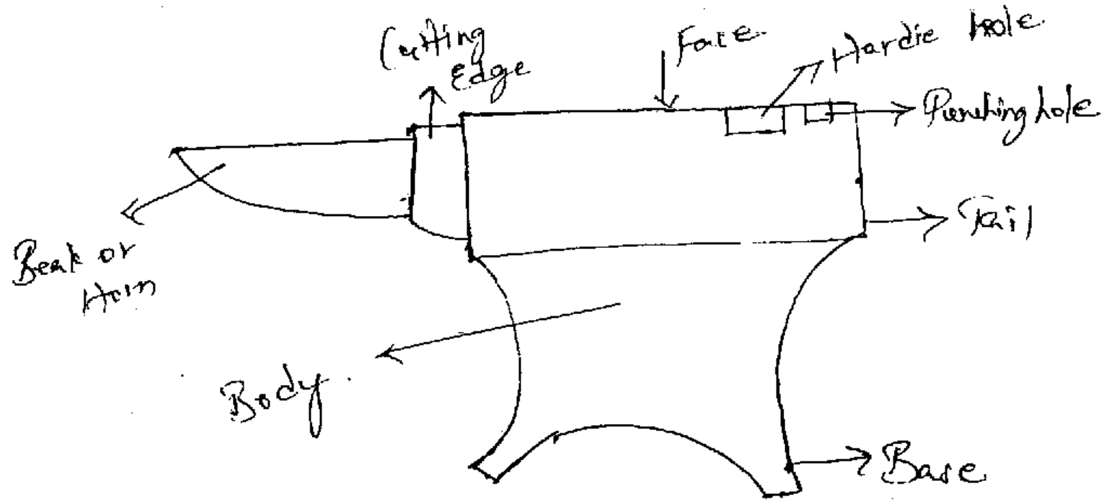
The major parts of furnace are hearth, tuyere, hood and water tank.

(a) Hearth carries fuel (which may be either coal or coke). Hearth is provided with fire brick lining to withstand the excessive heat produced due to combustion of fuel.
(b) Tuyere the nozzle in the centre of hearth. It is used to direct the air for combustion of fuel. The blower supplies the air through tuyere. A valve is incorporated in the air pipe, before the tuyere, to control the supply of air to furnace.
(c) Water tank may be provided in front of hearth for quenching and to prevent fire from spreading.



(2) Anvil:

It is block made of cast iron or steel on which forging work is carried out. It supports the work piece and is capable of with standing heavy blows of hammer. Apart from supporting work piece, its shape helps in doing other forging operations. The thickness of Anvil is 20 to 25 mm and weights approximately 150 kg.



The main parts of Anvil are:

Horn or Beak: It is used in bending the metal or forming curved shape.

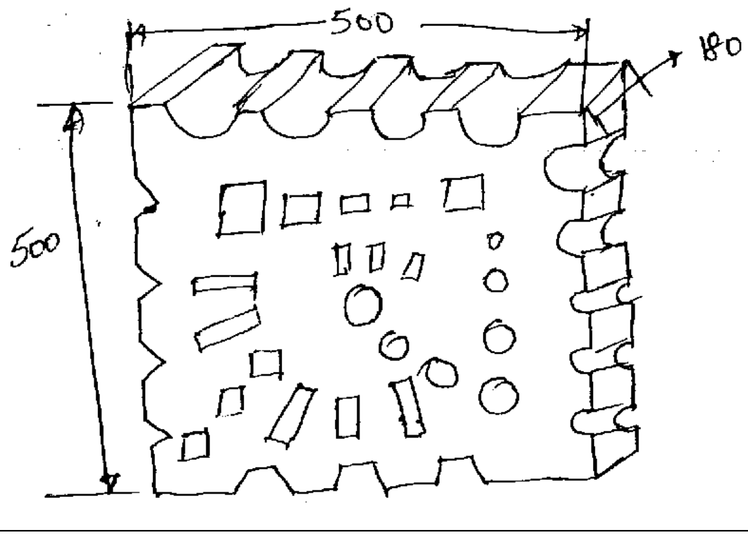
Chipping Block: It is the flat step provided between horn and anvil face. It may be used for supporting metal when cutting through chisel.

Face: It is the flat surface provided on the top of anvil.

Tail: The projected flat surface at the end of anvil is known as tail. It carries a square hole and round hole to accommodate various jobs and hand tools like fullers, swages etc…

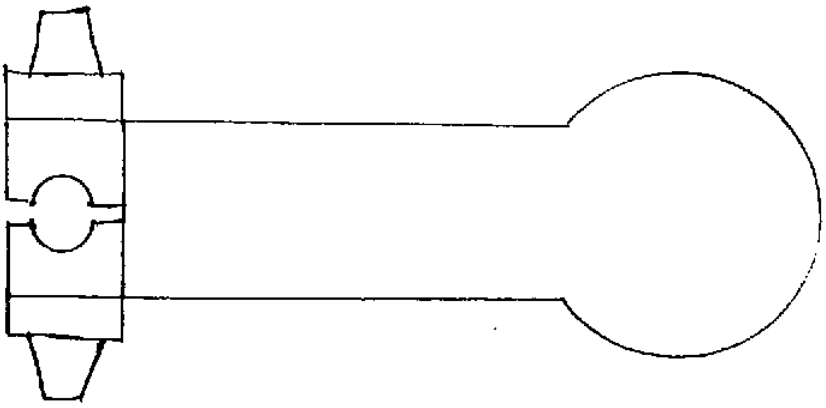
(3) Swage Block:

It is a block of cast iron or cast steel carrying number of holes of various shapes and size from top to bottom face. These holes are used in punching and their use prevents punch from spoiling by striking against hard surface. Swage block also carries number of different shapes and sizes. Those slots are useful for holding bars while bending, swaging etc…



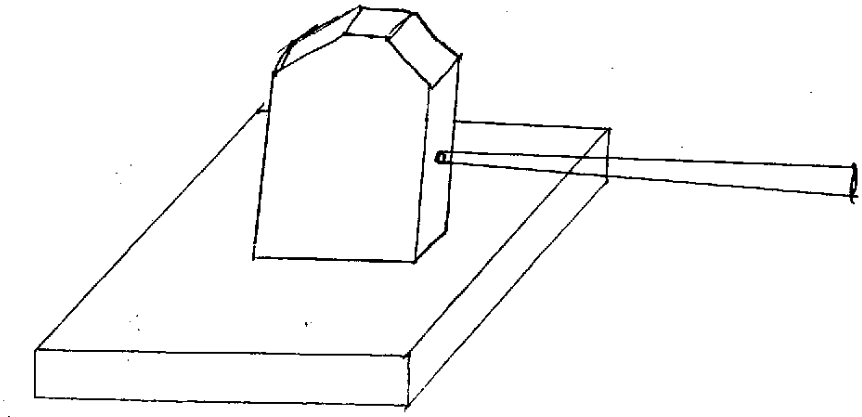
(4) Swages:

These are made of carbon steel. These are used for reducing and finishing the work pieces to round or hexagonal form. They are made in two halves called top and bottom swages. The two halves may be separate or connected by a strip of spring steel. Connected swages can be hold by single handed.



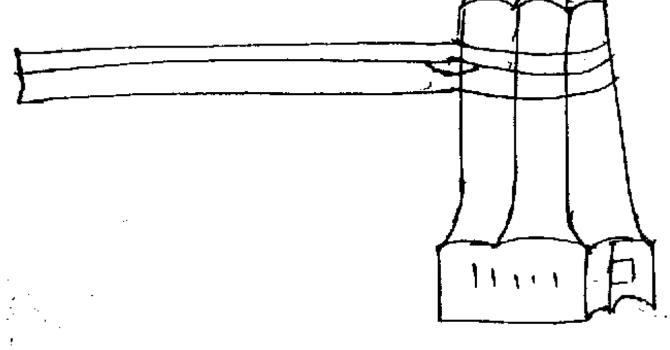
(5) Flatters:

They are used for finishing flat surfaces. The flatters may also be used after fulling or drawing to remove fullering marks. These are made with perfectly flat face of about 75mm square (or round).



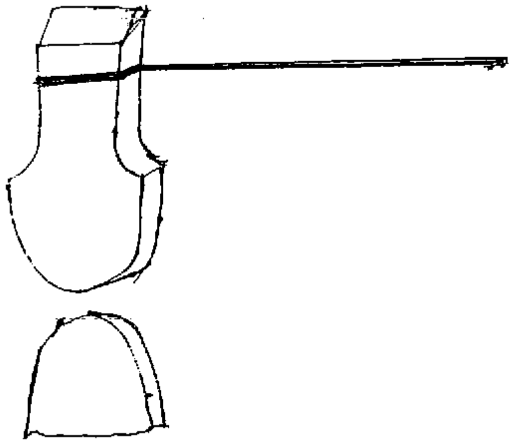
(6) Set Hammer:

Set hammer works like a flatter but it is a smaller tool. It does not have enlarged bottom face (like flatter) and is used for finishing in corners and confined spaces. The job may be supported on the anvil.



(7) Fullers:

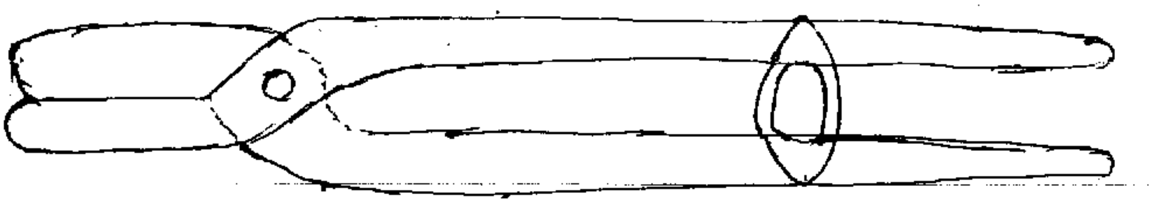
Fullers are used in necking down a work piece. They are made in two halves namely bottom and top fuller. The bottom fuller is held in anvil where as top fuller is held by means of handles or by tongs. The work piece is held between top and bottom fuller and then hammered to carry out fullering operation.



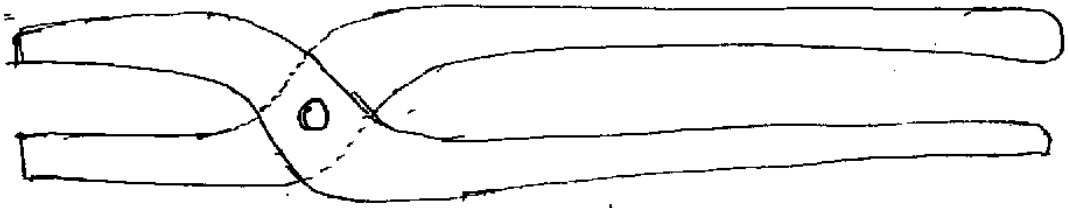
(8) Tongs:

Tongs are used to hold job during forging operations. Tongs are usually named after inside shape of jaws. Various types of tongs are:

(i) Flat Tongs: Used for gripping thin sections and small flat pieces.
(a) Open mouth
(b) Closed mouth



(a) Closed mouth tong.



(b) open mouth tong.

(c) Round Hollow tong.

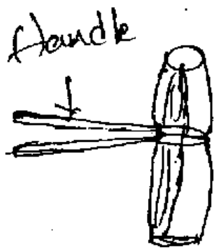
(ii) Tongs for round jobs: Used for holding round work pieces.
(a) Hollow bit
(b) Round mouth

(iii) Tongs for square jobs: Used for holding square or hexagonal jobs.
(a) square mouth
(b) Vee mouth

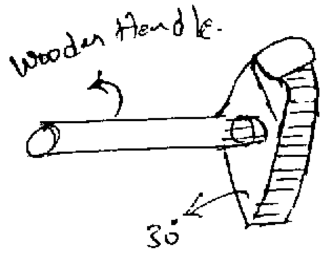
(iV) Pickup Tongs: Used for picking up jobs. Jaws are designed to pickup even small section.

(9) Chisel:

These are used for cutting metals and for making a notch before breaking. Chisels may be classified as hot chisel and cold chisels.



(a) Cold Chisel



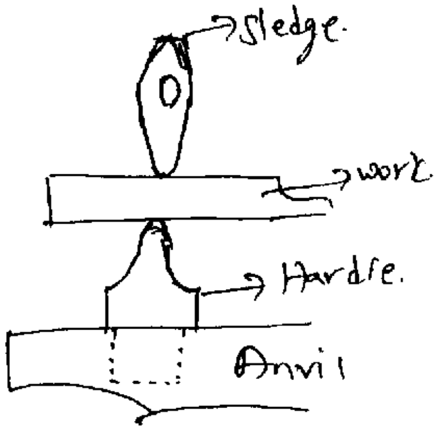
(b) Hot chisel.

Hot chisel: As name suggest, these are used for cutting hot metals. Included angle for hot chisel is 30°. The edge of chisel is slightly rounded for better cutting action. Hardening of these chisel is not necessary because the hot metal would re-soften it.

Cold Chisel: These are made up of carbon steel. The lip angle of cold chisel is 60° and it is edge hardened and tampered to provide more strength.

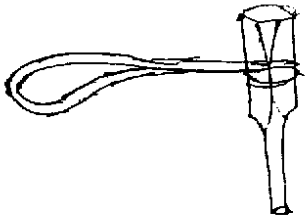
(10) Hardie Set:

When chisel are used in pair these are called hardie set. Pair consists of top tool which is a chisel and bottom tool, which is known as hardie. The hardie has a square shank which fits in the square hole of anvil face. The top tool (chisel) is held by black smith. Chisel may be fitted with a handle of metal wire to hold.

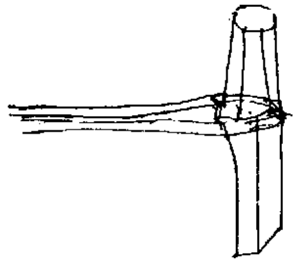


(11) Punches and Drifts:

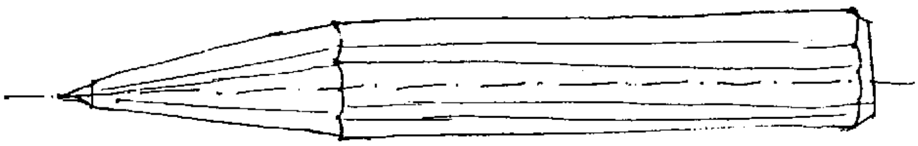
Punch is a tool used for producing hole in red hot metal. These holes are enlarged through a larger tapered punch called drift. Various types of punches and drifts are shown in below figure:



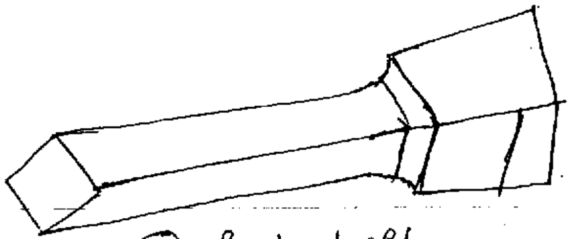
(a): Round Punch



(b) Square punch



(c) Centre Punch



(d) Simple drift

(12) Hammers:

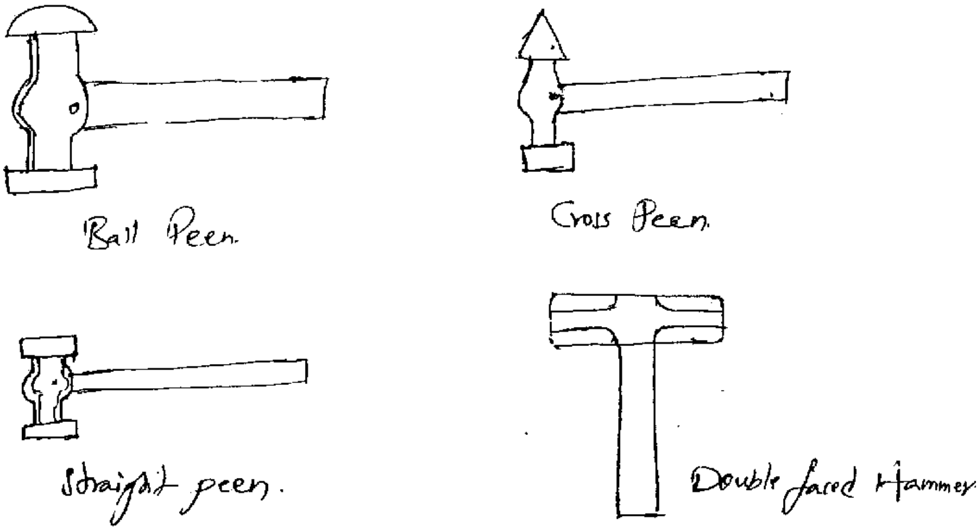
Hammers are major striking tool in fitting and smithy shop.

Hammers consist of a heavy iron body and wooden handle. The parts of hammer are peen, eye, neck and face. Depending upon the shape of peen hammers may be classified as,

(i) Ball Peen Hammer: Shape of peen is hemi – spherical ball.
(ii) Straight Peen Hammer: The peen is parallel to the axis of hammer (which passes through the eye).
(iii) Cross peen hammer: The peen is perpendicular to the axis of hammer (which passes through the eye).
(iv) Double faced hammer: The hammer has no peen formation and has flat faces at both ends.

Depending upon the size hammer may be classified as;

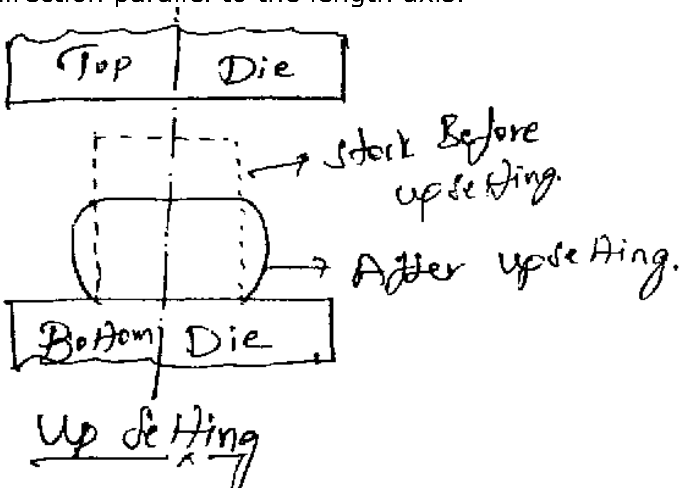
(i) Hand Hammer: Usually ball peen hammer of weight 1.0 to 2 kg.
(ii) Sledge Hammer: Usually double face hammer weight of 3 to 8 kg. It is used when heavy blows are needed.



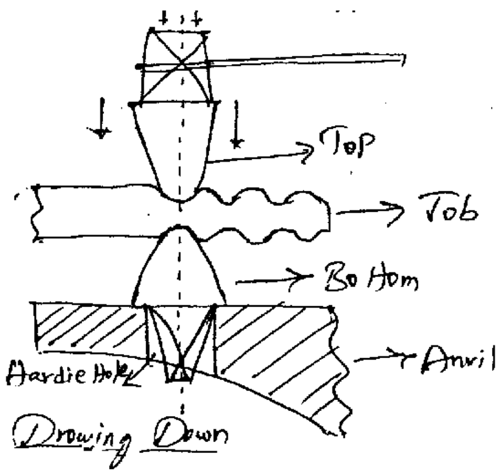
Basic Forging Operations:

For giving desires shape to the products the following operations are used in smithy shop by hand on an anvil.

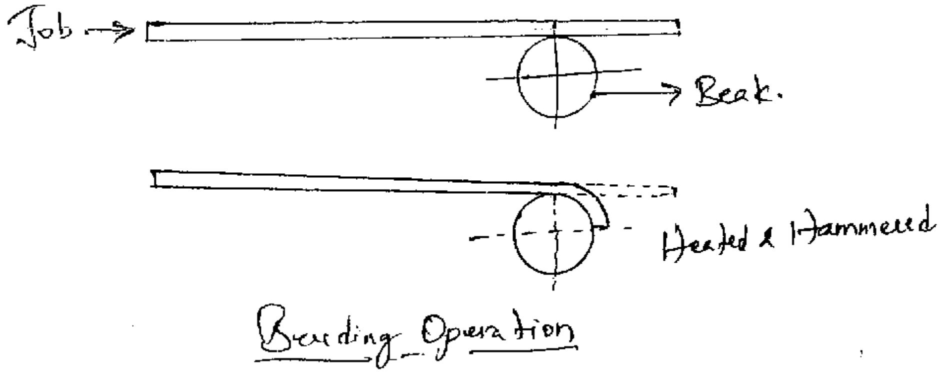
1. Upsetting: Upsetting is the process of increasing the thickness of a bar with a corresponding reduction on length by end pressure. The pressure is applied at the end of the bar against the anvil or clamping in vice and then hammering. For this, force is applied in a direction parallel to the length axis.



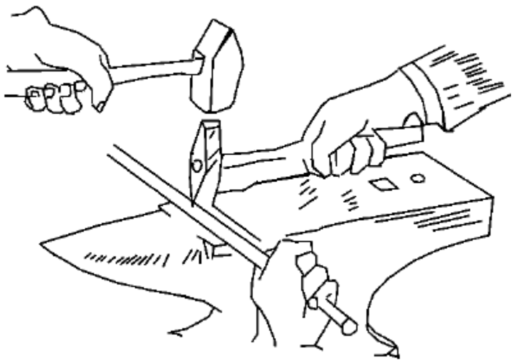
2. Drawing Down: Drawing down is used to reduce the thickness of the bar to increase its length. For this purpose, the force is applied in a direction of the length axis.



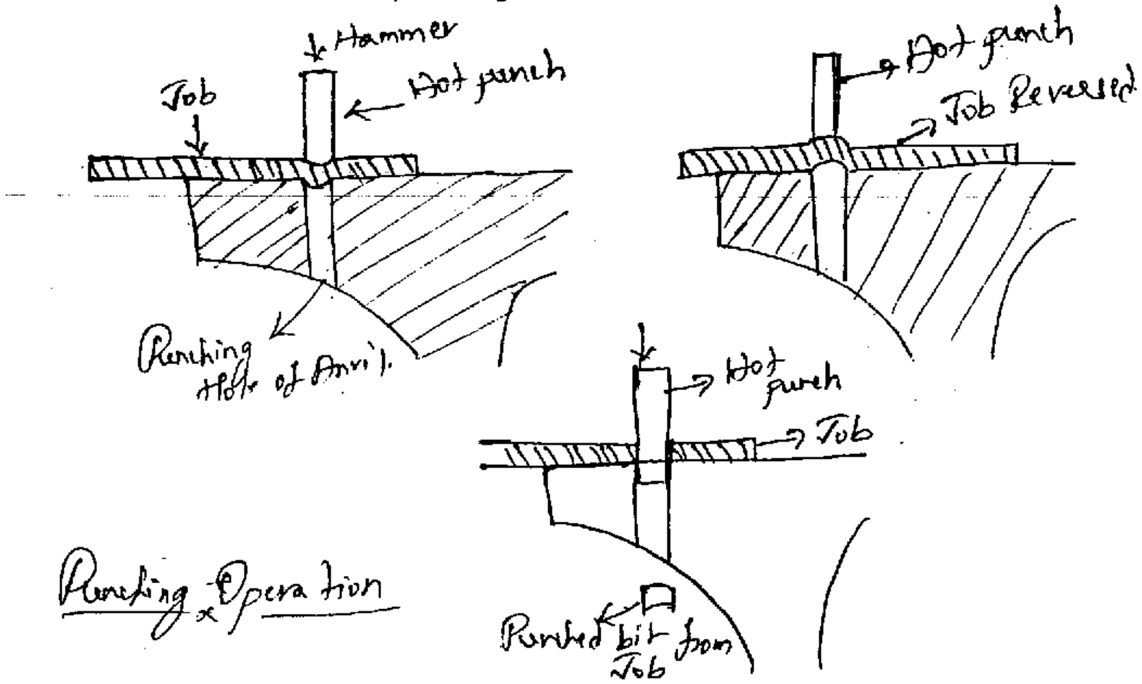
3. Bending: Bending is very common forging operation. This may be angular or curvilinear. It is done on the edge of the anvil face, over the anvil horn or by inserting the end in the pritchel hole and bending the bar with tong. The below figure shows the stages in bending bar over the horn of an anvil using a hammer.



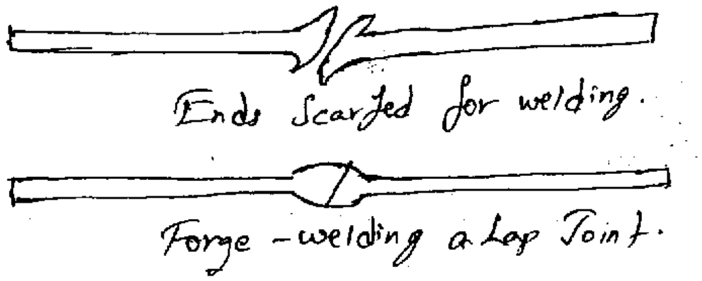
4. Cutting: Cutting off is a form of chiseling to cut a long piece of stock into several pieces of specified lengths. For hot chiseling the work pieces must be heated in a black smith's furnace. A notch is first made about one-half the thickness or diameter of the stock. Then the work must be tuned through an angle of 180° and the chisel is placed exactly opposite the notch and hit the chisel with hammer to cut the piece.



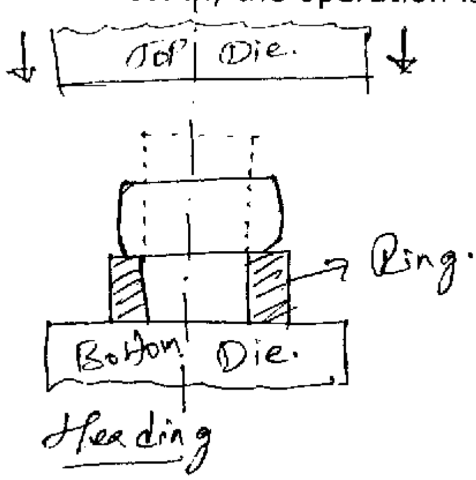
5. Punching: Punching operation is used for making holes in the work during forging. A punch is forced about half way through the work by striking it slightly with a hand or sledge hammer. The punch is removed, the work is turned over and the punch driven into the metal by a sledge hammer ad thus hole is made.



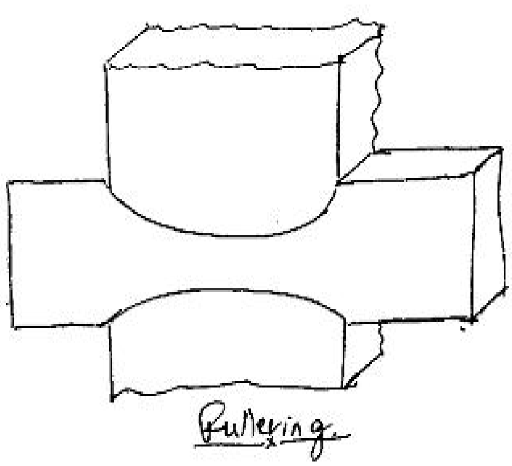
6. Welding: A forge weld is made by hammering together the ends of the two bars. In the lap weld, the ends of pieces to be joined must be upset and shaped slightly convex, so that when put together the junction takes place first at the center and extends to the edges. Wrought iron and mild steel can be satisfactory forge welded.

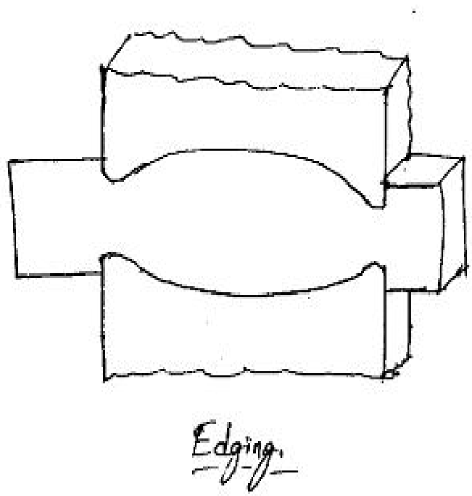


7. Heading: When the upsetting is done in such a way that the section of the stock is increased only on one end of the stock, the operation is called heading.



8. Fullering: It is the operation of reducing the stock between the two ends of the stock at a central place, so as to increase its length. The inclined surface of the die prevents material movement in the width direction because there is a pressure component acting in the direction of material flow. Repeated strokes, with the work piece rotated around its axis between strokes, allow substantial material redistribution.





9. Edging: The function of edging or rolling operation is to distribute the metal longitudinally by moving metal from the portion of the stock where if is in excess to the portion which is deficient in metal. For example, for forging a connecting rod from a bar stock, the metal will have to be moved longitudinally since the section of the rod varies along its length. This is an important operation in closed die forging.

10. Flattening: This operation is used to flatten the stock so that it fits properly into the finishing impression of a closed die.

11. Blocking: It is a forging operation which imparts to the forging its general but not exact or final shape. This operation is done just prior to finishing operation.

12. Piercing: Piercing is the operation done with the help of a punch to obtain blind or through holes in the metal. The pierced billet is further processed.

13. Swaging: It is the operation of reducing or changing the cross section area of diameters by revolving the stock under fast impact blows.

14. Coining: It is cold closed die forging operation (no flash) to obtain closer tolerances and smoother surfaces.

Forging Processes & Classification:

The process of reducing a metal billet between open dies or in a closed impression dies to obtain the required shape are called smith forging or impression die forging respectively. Depending on the equipment used, they are further sub divided as hand forging, press forging, drop hammer forging, mechanical press forging, upset or machine forging.

In general the methods of forging may be classified as follows:

(1) Open Die Forging (Smith Forging)

(a) Hand Forging (b) Power Forging
(c) Hammer Forging

(2) Closed Die Forging (Impression Die Forging)

(a) Drop Forging (b) Press Forging
(c) Machine Forging or Upset Forging

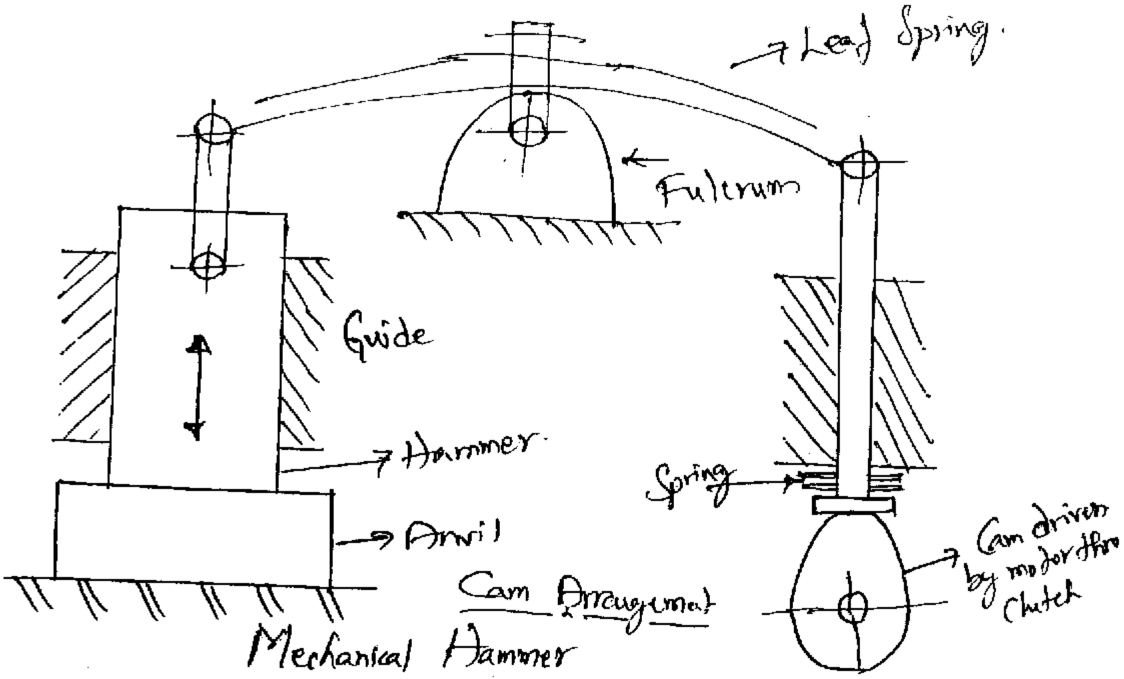
(1) Open Die Forging:

It is also called as Smith forging. In open die forging which is also called 'Hammer forging' or 'Flat die forging', the work piece is struck or pressed between two flat surfaces. Open die forging is used where number of components to be forged is too small to justify the cost of impression dies. The shapes most commonly used by open die forging are, bars, slabs or billets with rectangular, circular, hexagonal or octagonal cross sections, weldless rings and many other components of simple shapes. The accuracy of the component produced by this process is less.

- **(a) Hand Forging:** Smith forging is known as hand forging. It is used to produce a small number of light forgings.
- **(b) Power Forging:** Large components cannot be forged by hand. Moreover hand forging is lengthy process and requires repeated heating of metal. Machines which work on forgings by blow are called hammers, while those working by pressure are called presses.
- **(c) Hammer Forging:** In hammer forging the hammer is lifted up to a certain distance and then it is allowed to fall by gravity. Depending upon the lifting mechanism the hammers may be classified as:

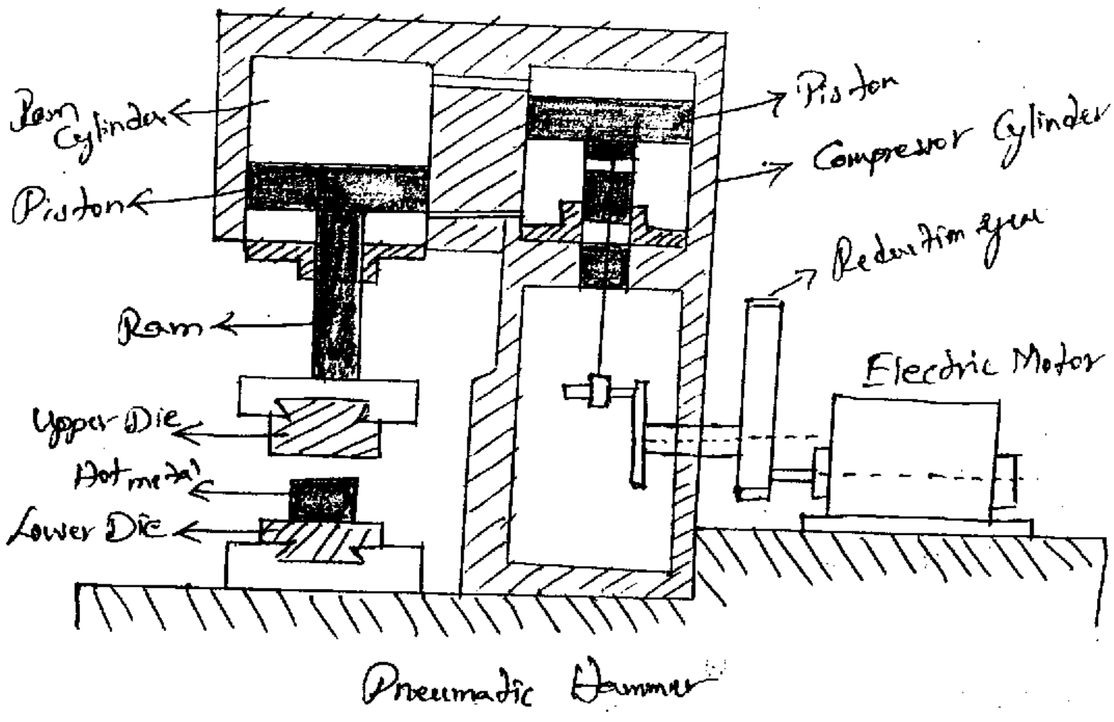
  - (i) Mechanical Hammers
  - (ii) Pneumatic Hammers
  - (iii) Steam or air Hammers

(i) Mechanical Hammers: The mechanical hammers are helve hammers, trip hammers and lever spring hammers. Lever spring hammer has constant lift. The arm is driven from rocking lever acting on an elastic rod. The rocking lever consists of a leaf spring. Mechanism is illustrated in below figure.



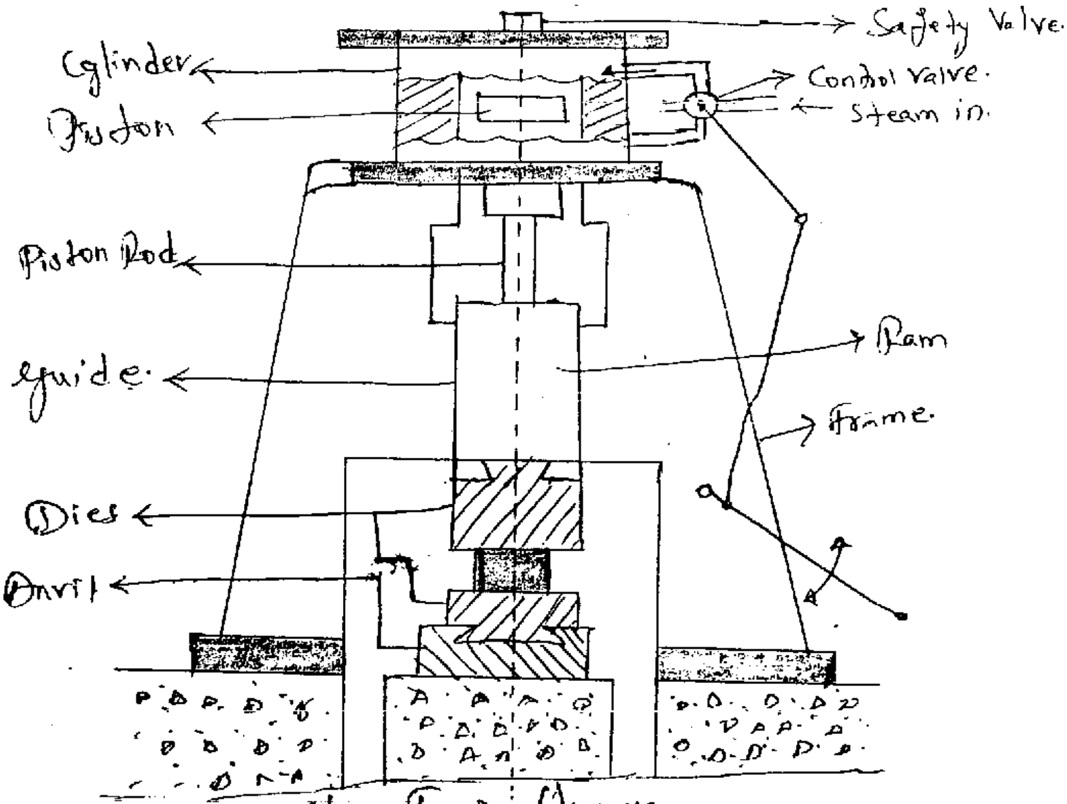
(ii) Pneumatic Hammers: Pneumatic hammer is used for smith forging of small parts. A pneumatic hammer has a built in compressor to provide a compressed air to ram cylinder. The upper die is connected to the lower end of the ram. The lower die is supported on the anvil.

When compressed air enters the ram cylinder from the top of the ram strikes the hot metal placed between the dies. To move the ram up, the compressed air enters from the bottom of the cylinder. Repeated blows are struck until the desired shape is obtained. These are operated at 70 to 190 blows per minute.



(iii) Steam or air Hammers: A steam hammer operates with the help of steam and air hammer requires compressed air for its operation. A steam or an air hammer may be (1) single acting (2) double acting. Steam or air pressure is usually between 6 to 8 kgf/cm2.

As shown in below figure steam entering from the top exerts pressure on its piston which moves downwards and upper die applies force on the hot metal to get deformed. The steam then enters from the bottom of the piston so that the piston moves upward. This cycle is repeated till the required shape is obtained.



Steam Forging Hammer

Die: Dies are devices used for shaping metal. The dies used in closed die forging or impression die forging may classified into two groups:

(i) Single Impression Die: This die contains only one cavity or impression which is the finishing impression. The preliminary forging operations are done by hand or on forge hammers, forging rolls etc… and only final finishing operation is done in the die cavity.

(ii) Multi Impression Die: This die contains finishing operation and one or more auxiliary impressions for preliminary forging operations. The final shape of a part is progressively developed over a series of steps from one die impression to the next. Generally multi impression dies are very expensive to make and are employed only when the quantity to be made is sufficiently large.

Advantages of Multi – Impression Die:

1. Complete sequence of forging operations can be carried out on one equipment only avoiding the use of auxiliary forging equipment.
2. Use of multi impression dies is particularly suited for particularly suited for production of small and medium sized forgings in large quantities as this method gives 2 to 3 times the production compared with the method of production using a single die.

3. All the preliminary operations can be performed on these dies with good ease. The use can be prepared to fairly accurate dimensions. Besides this more accurate forgings are prepared.
4. Wastage of forging metal is reduced.
5. Use may not be reheated for the finishing impression.
6. Initial die cost becomes insignificant in case of high output.
7. Finishing impression lasts ling, because much of the load is taken by blocking impression.

(2) Impression Die Forging:

It is also known as closed die forging. In closed – die forging, cavities or impressions are cut in the die block, in which the metal is forced to take its final shape and dimensions. The flow of metal is limited by surfaces of the impressions. Closed die forgings have the following characteristics.

1. Saving the time as compared to open die forging.
2. Makes good utilization of work piece materials.
3. Excellent reproductivity with good dimensional accuracy.
4. Forgings are made with smaller machining allowances, thus reducing considerably the machining time and the consumption of metal required for the forging.
5. Forgings of complicated shaped can be made.
6. The equipment for closed die forging does not require highly skilled workers.
7. The grain flow of metal can be controlled ensuring high mechanical properties.
8. Method is suited for rapid production rate.
9. Cost of tooling is high, therefore suitable for large production runs.

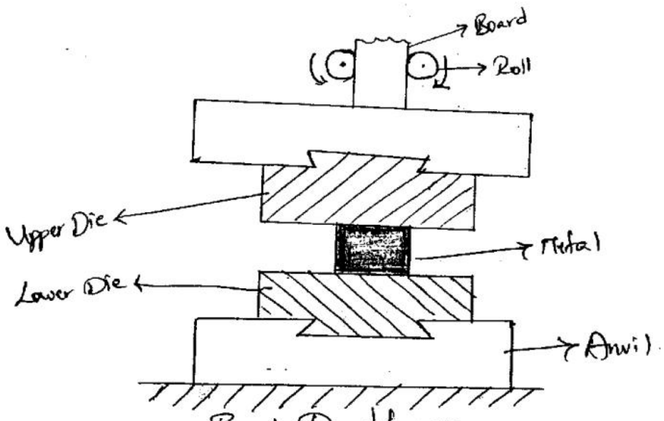
It is used to make more complex shapes of products with greater accuracy. After forging operations, the product should be trimmed to remove flash.

(a) Drop Forging:

The ram is raised to a definite height and then it is allowed to drop or fall freely under its own weight. The commonly used drop hammers are:

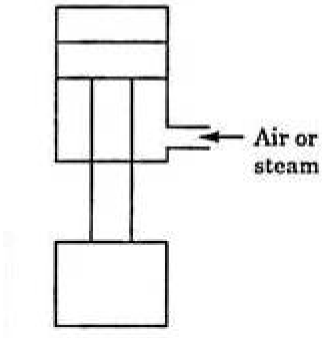
(i) Board hammer or gravity drop hammer
(ii) Air lift hammer
(iii) Power drop hammer

(i) Board hammer or gravity drop hammer: In these hammers, tam is fastened to a hard board as shown if below figure. The board is lifted up by two counter revolving rolls. When the rolls are released, the ram falls down producing a working stroke. The height to which the board is lifted determines the striking force of this gravity hammer.



Board Drop Hammer

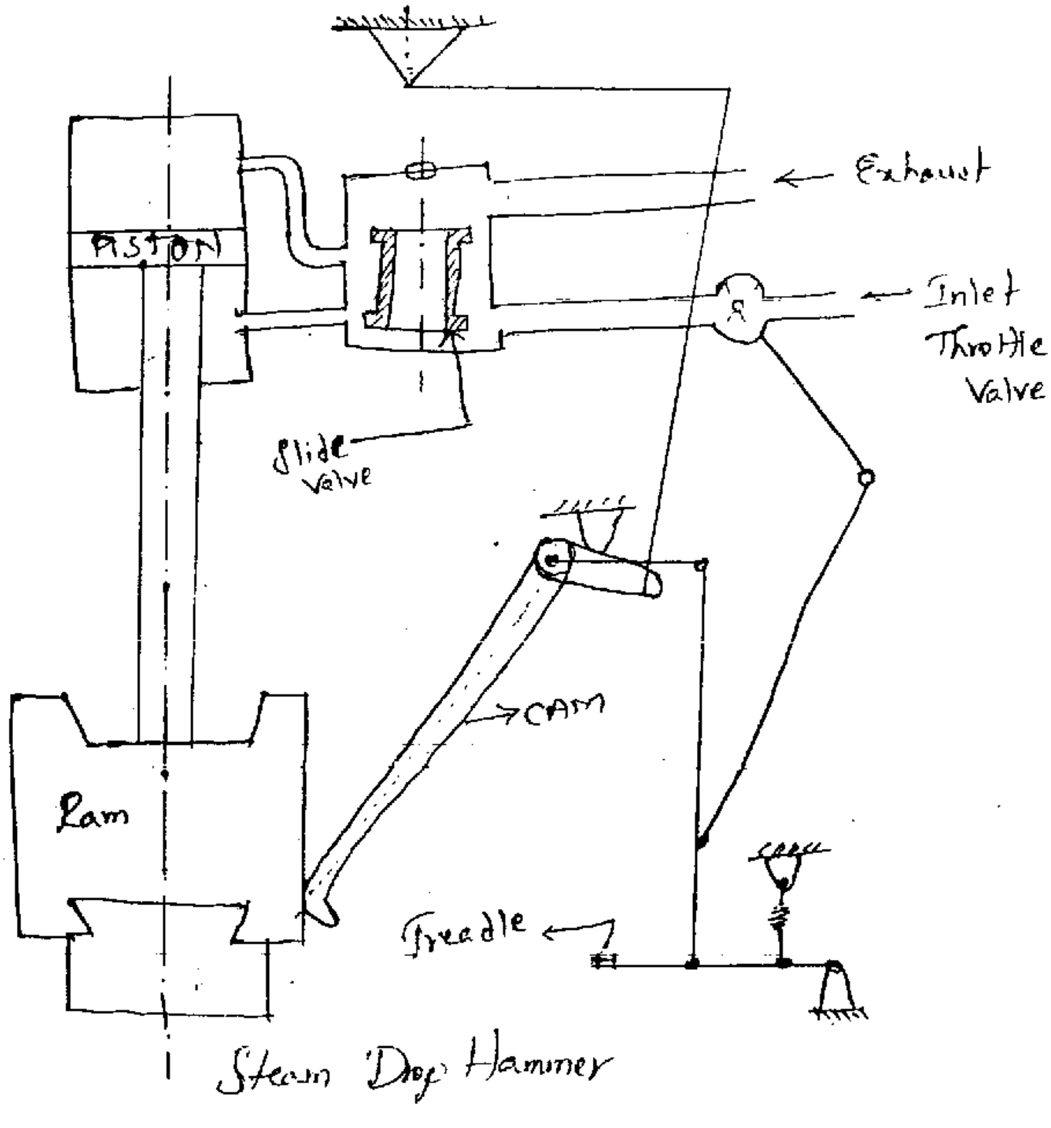
(ii) Air lift hammer: These hammers use compressed air to lift the ram which is then allowed to fall by gravity similar to the board drop hammers.



Air lift hammer

(iii) Power drop hammer: They use air or steam. They are similar to board drop hammers except that steam or air piston and rod are substituted for board lifting mechanism. They are largest of forging hammers and are made from 450 to 25,000 kgs falling weight hammers.

A variation of the hammer discussed above is the 'gravity drop hammer' or 'air lift hammer'. In this design, the steam or air that is used to lift the ram is suddenly released to allow the ram to fall freely under gravity.



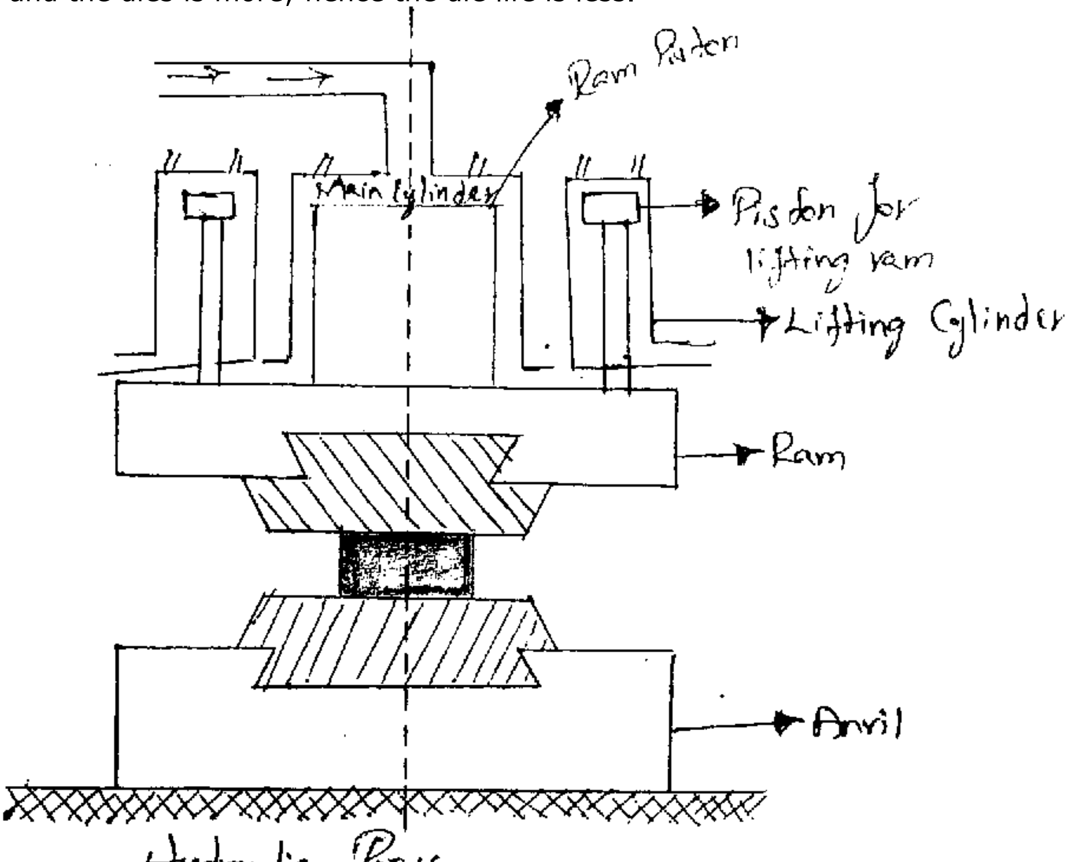
Steam Drop Hammer

(b) Press Forging: The press forging is also done in impression dies. In press forging, the metal is shaped not by means of a series of blows as in drop forging, but by means of continous squeezing action. The manner in which the metal deformation takes place in press forging substantially differs from that of hammer forging. Blow of hammer works only in the surface layer of forging and deformation does not penetrate into the volume of the metal. Squeezing pressure of a press applied to the forging gradually increases and penetrates deep into the metal.

The two types of presses used are:

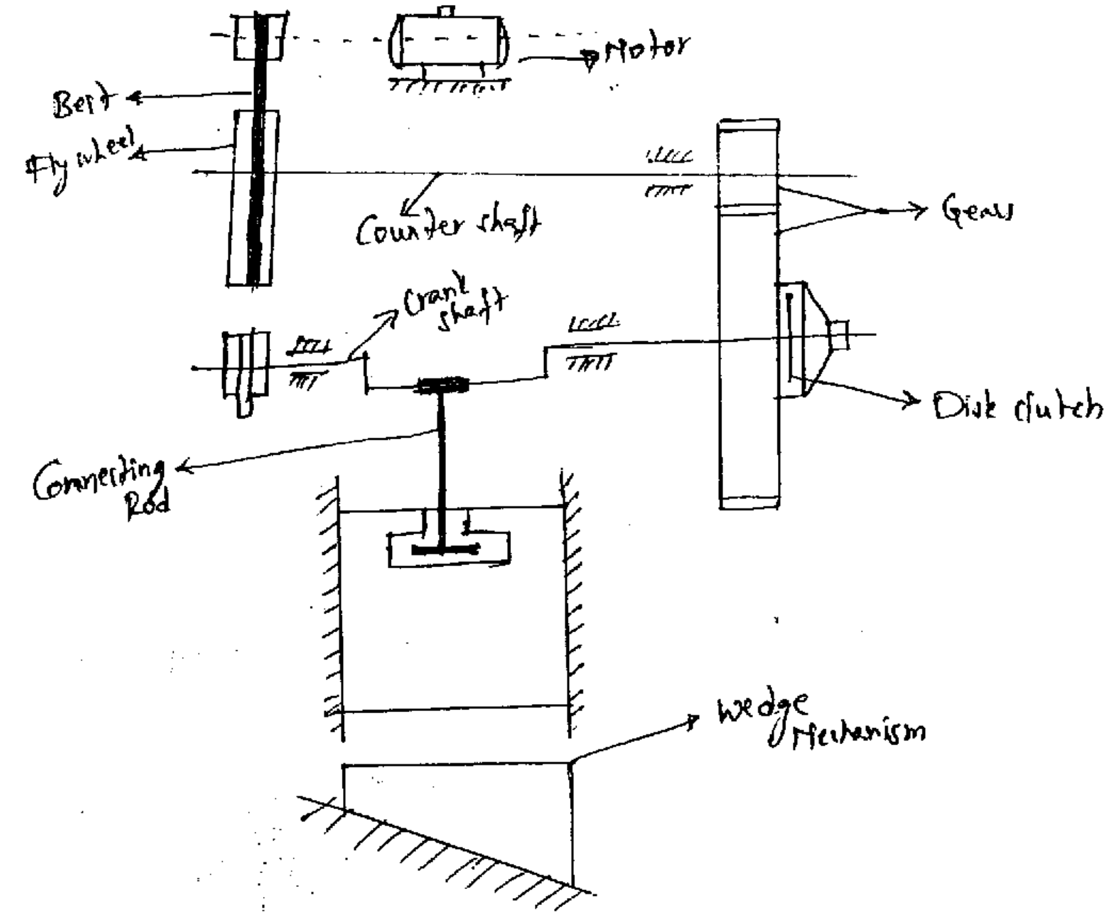
(i) Hydraulic Press (ii) Mechanical Press

(i) Hydraulic Press: The following figure illustrates a hydraulic press. The press is operated by pump which increases the pressure in the oil or water. This pressure is transmitted to main cylinder to move the piston (ram) downward to squeeze the hot metal between the dies. The lifting cylinder raises the ram up. In a hydraulic press, pressure can be changed as desired at any point in the stroke by adjusting the pressure control valve. This will help in controlling the rate of deformation according to the metal being forged. But in hydraulic press, the contact time between the work piece and the dies is more; hence the die life is less.



Hydraulic Press

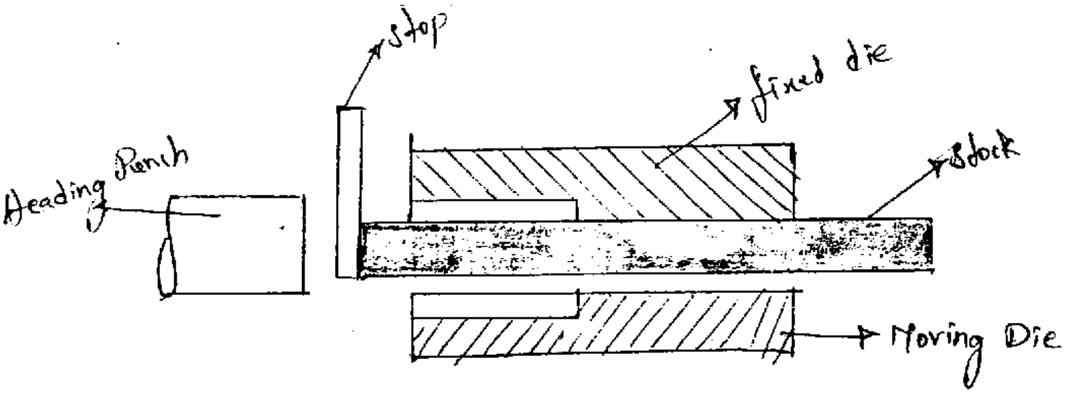
(ii) Mechanical Press: Crank type mechanical press is shown in below figure. An electric motor drives the flywheel mounted on the counter shaft by means of a belt drive. Torque from the counter shaft is transmitted to the crankshaft by gearing. From the crankshaft, the reciprocating motion is given to the ram with the help of connecting rod. The bottom die is locked in position by means of wedge mechanism. Disk clutch is used to start and stop motion of ram, which is brought to a gradual stop by means of a brake. Mechanical press is faster than hydraulic press and operates at about 25 to 100 strokes per minute.

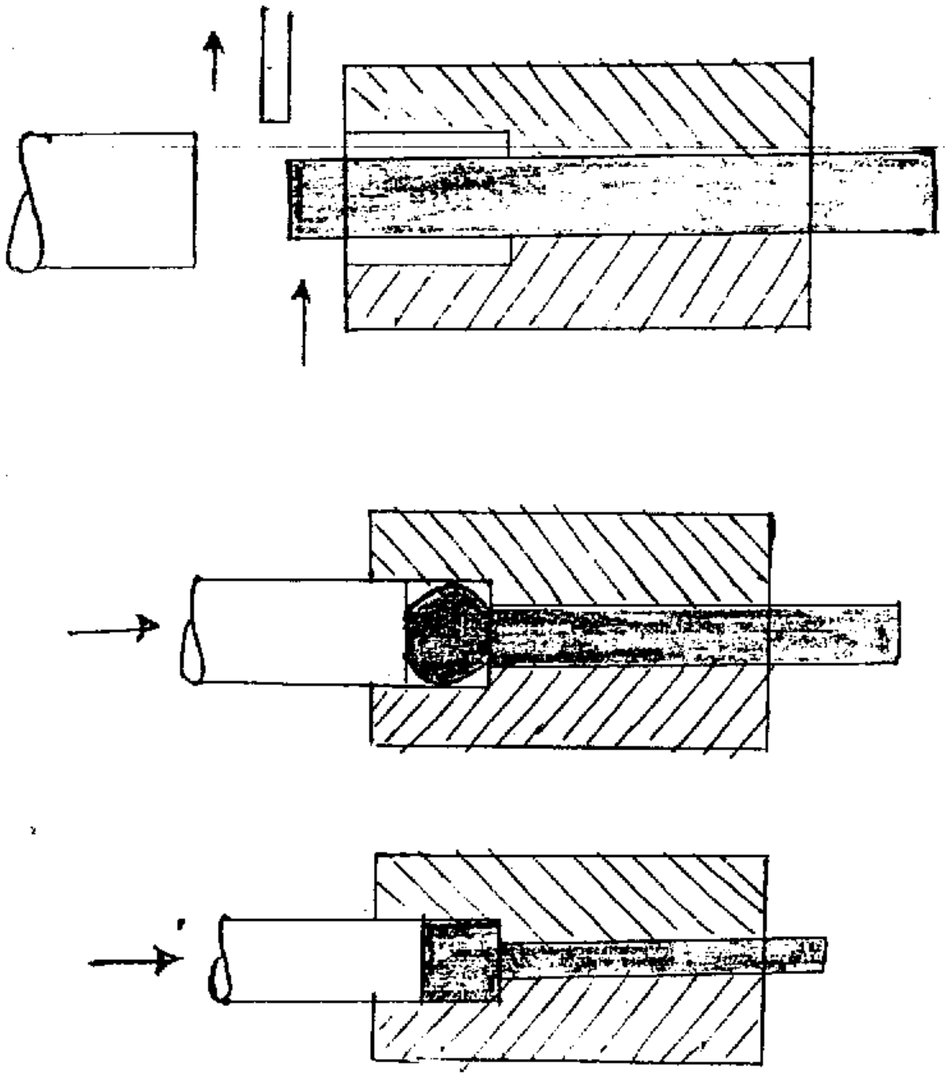


Crank Type Mechanical Press.

(c) Machine Forging or Upset Forging: Unlike press forging, it operates in horizontal direction. As it involves the upsetting operation, it is simply called as upset forging. Upset forging was originally developed for heading operations. But today its scope has been widened to perform a large variety of operations such as punching, bending, cutting and squeezing etc…

The forging machine consists of a heavy cast steel body in which three main components, stationary die, moving die and heading punch are properly secured. The sequence of operation of machine is explained in the below figure. First the bar stock of one end heated is placed between the fixed and movable halved of the set of dies up to stop. Next the moving die grips the bar stock and at the same time, a recess is formed in the closed dies for shaping the projected stock. Stop is then brought to its initial position. Now the heading punch advances to upset the bar end and forms the finished forging.



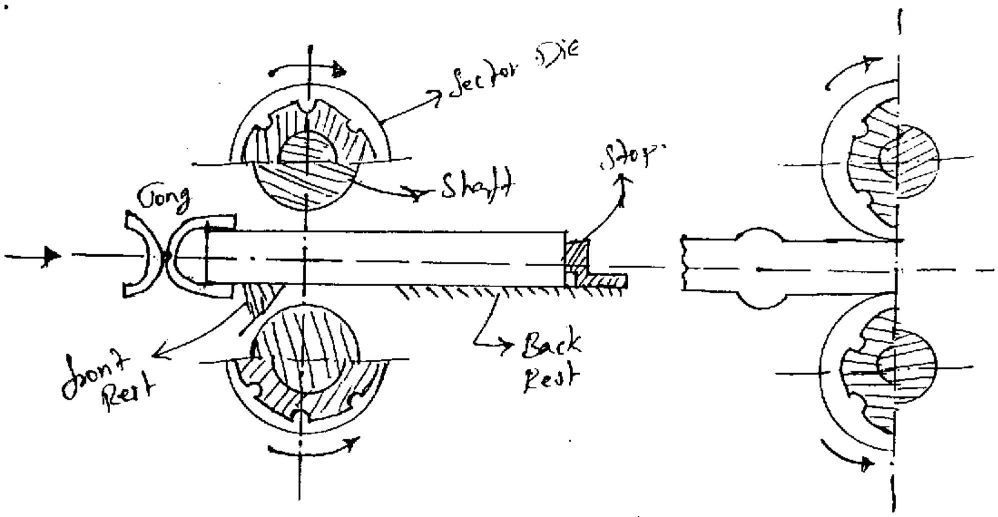


Up Set forging - Steps.

Roll Forging:

A variety of shapes having straight or tapered reduced sections may be forged with the aid of rolls. Here, the rolls are not completely cylindrical but are sector shaped to permit the tock to enter between the rolls. These roll segments have one ore more sets of grooves of impart a desired shape to the piece being forged. When the rolls are in the open position, the heated stock is advanced upto a stop. As the rolls rotate, they grip and roll down the stock. The stock is transferred to a second set of grooves. The rolls turn again and so on until the piece is finished. Like this, the bar stock can be increased in length, reduced in diameter and changed in section as desired.

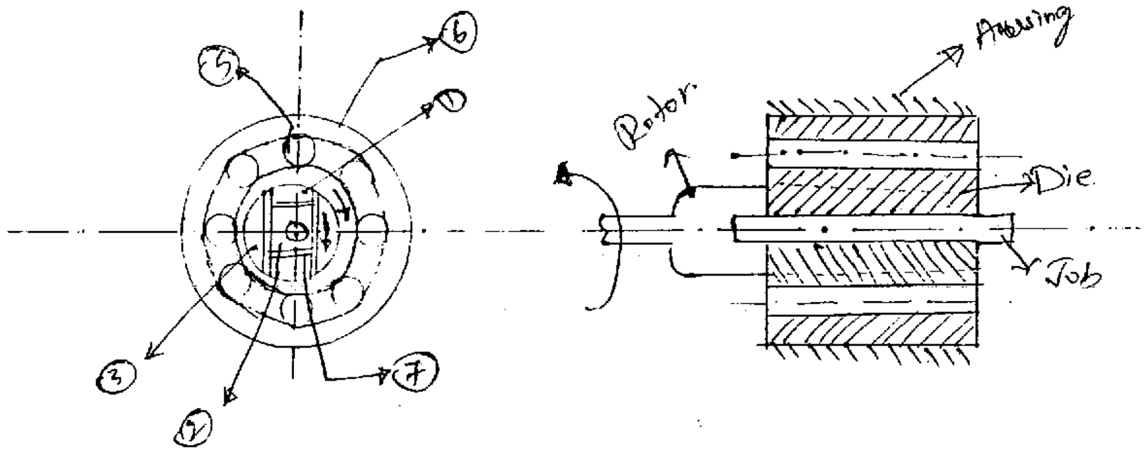
Roll forging being a rapid process; it can be efficiently used for the preliminary reduction of forging stock as a preparation for subsequent die forging, as well as for the production of certain straight and tapered forgings, for example levers, leaf springs, axles and arrow and spear type parts.



Rotary Forging or Swaging:

Round bars or tubing's can be reduced in their diameters by a process called "Rotary forging or Swaging". The process can be done both in the hot and cold state. However, cold working is preferable because of the greater ease of handling and better surface finish obtained. The figure shows schematically the rotary forging process. Small rams 1 with dies 2 inside the spindle head 3 slot are brought together to reduce the work-piece and separate again under the action of centrifugal force or springs. The spindle head is housed inside cage 4 with rollers 5 which rest from the outside on annular ring 6. As the spindle rotates, the small rams run against the rollers and so strike blows from various directions upon the job fed axially which is reduced in diameter by drawing out process.

Reduction is controlled by means of liners 7. The other applications of this process are fabrication of stepped and tapered shafts, pipes with forged out ends etc. Capacity of hot reduction is 150 mm in terms of rod diameter, and 300 mm and the surface quality is as good as that in machining.



The advantages of this process are:

1. Low initial investment
2. Easy maintenance
3. Low tool cost
4. Low labour cost
5. Rapid production
6. Consistency of the product

The major limitations of rotary swaging are that the process is limited to parts of symmetrical cross section only.

Advantages of Forging:

The various advantages of forging are as follows:

1. Forgings have a high strength and offer resistance to impact and fatigue loads.
2. Forging improves the grain structure of metal and hence its mechanical properties.
3. Close tolerances
4. Less machining or no machining in some cases.
5. Smooth surface

Limitations of Forging:

1. High tool cost.
2. High tool maintenance
3. The rapid oxidation of metal surfaces at high temperature results in scaling which wears the dies.

Defects in Forging Parts:

Various surface and body defects may be observed in forging. The kind of defect depends upon a lot off factors such as forging process, poor quality of stock, improper die design, uneven cooling of stock after forging etc… The most commonly found forging defects are as follows:

1. **Mismatch:** This is due to the misalignment between the top and bottom forging dies. This may be caused due to loose wedges. This results in a lateral displacement between the portions of the forging.
2. **Scale Pits:** These are shallow surface depressions caused by not removing scale from the dies. The scale is worked into a surface of the forging. When this scale is cleaned from the forging, depression remains which are known as scale pits.
3. **Cold Shuts or Laps:** Cold shuts or laps are short cracks, which usually occur at corners and at right angles to the surface. They are caused by metal surface folding against itself during forging. Sharp corners in dies can result in hindered metal flow, which can produce laps.
4. **Unfilled Shapes:** This defect is similar to misrun in casting and occurs when metal does not completely fill the die cavity. It is caused by using insufficient metal or insufficient heating of the metal.
5. **Dents:** Dents are the result of careless work.
6. **Burnt and over Heated Metal:** This defect is due to improper heating conditions and soaking the metal too long time.
7. **Cracks:** Cracks occur on the forging surface may be longitudinal or transverse. These are due to bad quality of ingot, improper heating, and forging at low temperature.
8. **Fins and Rags:** These are small projections or loose metal driven into forging surface.
9. **Dirt, Slag and Sand:** These may be present on the surface of the forging due to their presence in the ingot used for forging.
10. **Internal Cracks:** Internal cracks in forging can result from too drastic a change in the shape of the raw stock at too fast a rate.

UNIT – 5: Plastics and Metallurgy

- **Introduction**
- **Polymers**
- **Polymerization**
- **Plastics**
- **Types of Plastics**
- **Properties of Plastics**
- **Comparison between Thermosetting plastics and Thermoplastics**
- **Advantages of Plastics**
- **Disadvantages of Plastics**
- **Applications of Plastics**
- **Methods of Processing**

Introduction:

Plastics belong to the family of organic materials. Organic materials are those materials are derived directly from carbon. They consist of carbon chemically combined with hydrogen, oxygen and other non-metallic substances, and their structures, in most cases, are fairly complex. The large and diverse organic group includes the natural materials: wood, coal, petroleum, natural rubber, animal fibers and food, which have biological origins. Synthesis include the large group of solvents, adhesives, synthetic fibers, rubbers, plastics, explosives, lubricants, dyes, soaps and cutting oils etc. which have no biological origins. Of them plastics and synthetic tubers termed as "Polymers".

Polymers:

The term "polymer" is derived from the two Greek words: poly, meaning "many", and meros meaning "parts" or "units". Thus polymers are composed of a large number of repeating units (small molecules) called monomers. The monomers are joined together end-to-end in a polymerization reaction.

The most common polymers are those made from compounds of carbon, but polymers can also make from inorganic chemicals such as silicates and silicones. The naturally occurring polymers include: protein, cellulose, resins, starch, shellac and lignin. They are commonly found in leather, fur, wool, cotton, silk, rubber, wood and many others. There are also synthetic polymers such as polyethylene, polystyrene, nylon, Terylene, Dacron etc… termed under plastics, fibers and elastomers. Their properties are superior to those of the naturally occurring counterparts. Our concern here is therefore with synthetic polymers, also called plastics or resins.

Polymerization: The process of linking together of monometers, that is, of obtaining macromolecules is called "polymerization". It can be achieved by one of the two processing techniques i.e., Addition Polymerization and condensation Polymerization.

Polymers can be divided into three broad divisions: plastics, fibers and elastomers. Plastic derive their name from the fact that in a certain phase of their manufacture, they are present in a plastic stage that is acquire plasticity, which makes it possible to impart any desired shape to the product. Plastics fall into a category of known chemically as high polymers.

Plastics:

The "Plastics" is a term applied to compositions consisting of a mixture of high molecular compounds and fillers, plasticizers, stains, and pigments, lubricating and other substances, some of the plastics can contain nothing but resin.

The word plastics is from the Greek word Plastikos, means which are moulded and shaped. Plastics can be easily machined, formed and joined into required shapes. Hence, plastics find place in engineering materials and domestic applications. Plastics are available in rods, sheets, films and tubes.

Types of Plastics:

Plastics are classified on the broad basis of whether heat causes them to set (thermosetting) causes them to soften and melt (thermoplastic).

Plastics are classified as,

(a) Thermo setting plastics
(b) Thermoplastics

(a) Thermosetting Plastics: These are formed to shape with heat, with or without pressure, resulting in a product that is permanently hard. The heat first softens the material, but as additional heat or special chemicals are added, the plastic is hardened by chemical change known as "polymerization" and cannot be resoftened. Thermosetting plastics are phenol-formaldehyde. Urea formaldehyde, epoxy resins etc. Products made by thermosetting plastics are T.V cabinets, telephone receivers, camera bodies and automobile parts.

(b) Thermoplastics: Thermoplastics under go no chemical change in moulding. They remain soft at elevated temperatures until they are hardened by cooling. These plastics can be reused or recycled by melting and remoulding. Most commonly used thermoplastics are polystyrene, polytene, P.V.V. (polyvinyl chloride) Nylon, Teflon etc… Products made by thermoplastics are photographic films, insulating tapes, hose pipes etc…

Properties of Plastics:

Their great variety of physico chemical and mechanical properties and the ease with which they can be made into various articles have found plastics their wide application in the engineering and the other industries.

1. Their comparatively low density, substantial mechanical strength higher strength – to – weight ratio and high anti friction properties have enabled plastics to be efficiently used as substitute for metals.
2. With certain special properties, plastics can sometimes replace ferrous metals.
3. From the productions point of view, their main advantage is their relatively low melting points and their ability to flow into a mould.
4. Simple processing to obtain machine parts. Generally there is only one production operation required to convert the chemically manufactured plastic in to a finished article.
5. Good damping capacity and good surface finish of the product.
6. The high heat and electric insulation of plastics permits them to be applied in the radio and electrical engineering industries as dielectrics and as substitutes for porcelain, ebonite, shellac, mica, natural rubber etc…
7. Their good chemical stability when subjected to the action of solvents and certain oxidizing agents, water resistance, gas and steam proof properties enable plastics to be used as valuable engineering materials in the automobile and tractor, ship building and other industries.

Comparison between Thermosetting plastics and Thermoplastics:

Thermosetting plastics
1. Once hardened and set, they do not soften with the application of heat.
2. These are stronger and harder.
3. Objects made by these plastics can be used at comparatively high temperatures.
4. These are supplied in monomeric or partially polymerized form in which these are either liquids or semi solids.
5. T.V. Cabinets, Automobile parts are made by these plastics.

Thermoplastics
1. They can be repeatedly softened by heat and hardened by cooling.
2. They are comparatively softer and less strong.
3. Objects made by thermoplastics cannot be used at higher temperatures as these lend to soften under heat.
4. These are usually supplied as granular material.
5. Insulating tapes, photographic films are made by these plastics.

Advantages of Plastics:

1. Light in weight compared to metals.
2. Excellent surface finish.
3. Close dimensional tolerances.
4. Moisture and corrosion resistance.
5. Easy to shape and mould.

Disadvantages of Plastics:

1. Low strength.
2. Low heat resistance.
3. Deteriorate in sunlight.

Applications of Plastics:

Plastics find applications in manufacturing of:

1. Photo films in film industry.
2. Insulating tapes
3. Electrical parts like plugs, switches etc…
4. Radio, T.V. cabinets
5. Furniture like chairs, tubs
6. Telephone receivers
7. Camera bodies
8. Gears and Bearings
9. Toys, bottles, bucket etc…
10. Hose pipes
11. Automobile parts

Methods of Processing:

(a) Moulding of thermoplastics

1. Injection Moulding
2. Blow Moulding
3. Extrusion
4. Thermoforming
5. Calendering

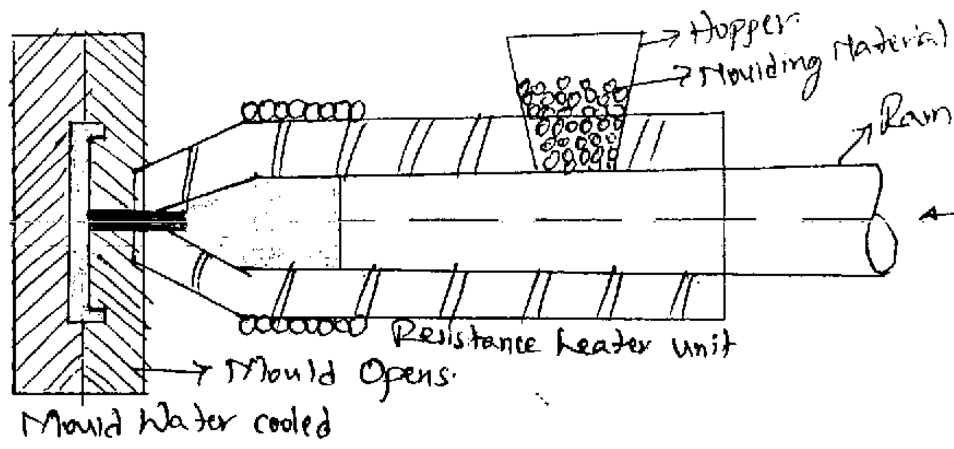
(b) Moulding of thermosetting plastics

1. Compression moulding
2. Transfer moulding

(a)1. Injection Moulding:

Injection moulding machines are somewhat similar to those used for die casting. In this method, the moulding material in the form of granules or pellets is fed through the hopper into the cold end of the injection cylinder. Then the injection ram forces the powder into the heating section of the cylinder where its temperature is raised to 300°C. Then the ram is moved forward by applying hydraulic pressure to inject the soften material through die into water cooled mould. After the mould is filled, it is allowed to cool and harden. Then the ram is retracted, the mould is opened and the product is ejected.

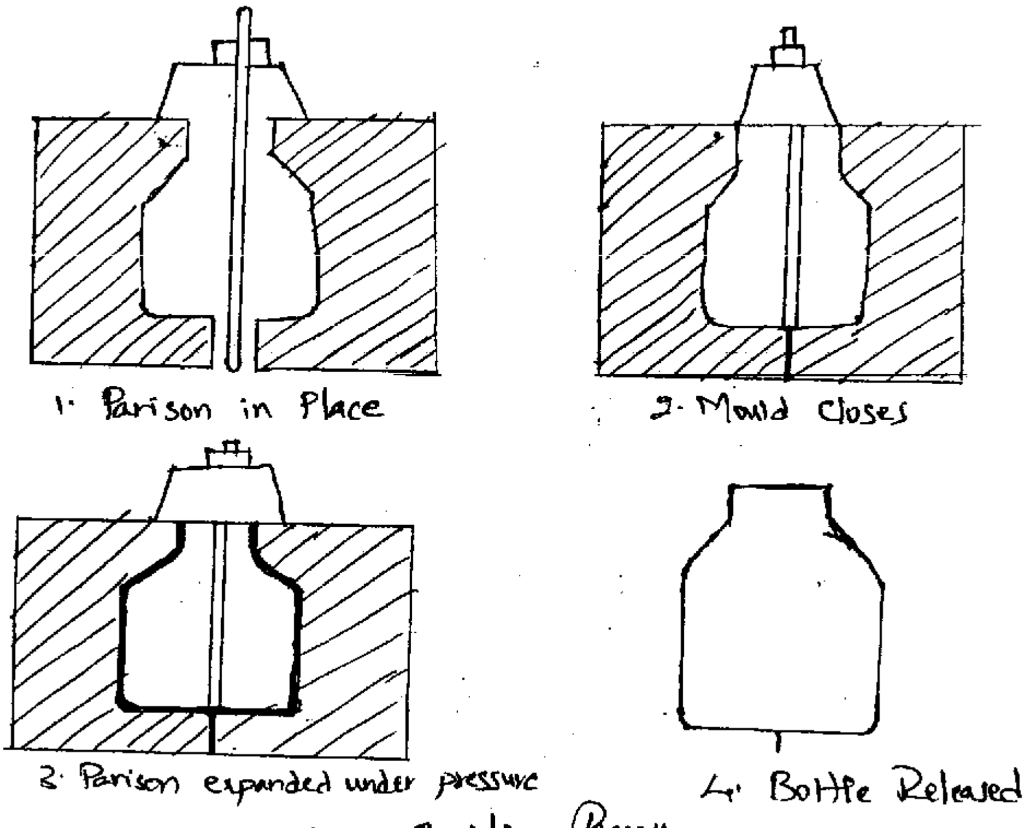
Injection moulding machines have a high production capacity; some can produce from 12 to 16 thousand parts per shift. This method is suitable for making parts with complex threads and intricate shapes. Typical parts include: Cups, containers, housings, tool handles, toys, knobs, plumbing fittings, electrical and communication components such as telephone receivers etc…



Injection Moulding.

The limitations of the process are: Equipment of cylinder and die should be non-corrosive. Also reliable temperature controls are essential.

(a)2. Blow Moulding:

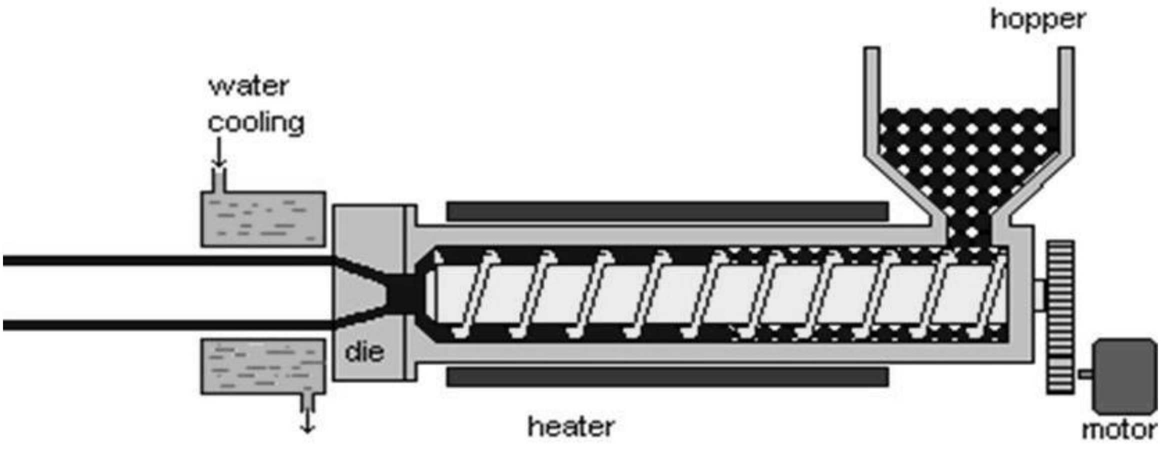


Blow Moulding Process.

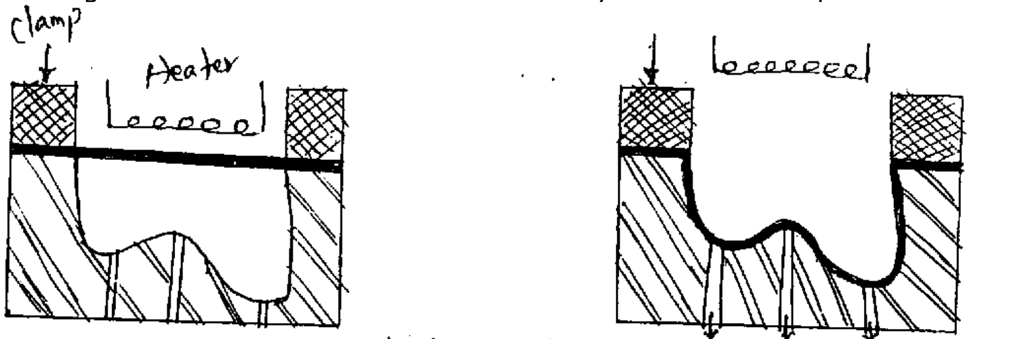
The blow moulding commences with the extrusion of heated tubular piece of plastic known as parison which is transferred to the two piece mould. The parison is gripped in the two-piece mould and its bottom end is sealed. Compressed air is blown into the parison to force the plastic against the walls of water cooled mould. Air pressure ranges from 0.7 to 10 kg/cm2. The mould is allowed to cool and then opened to remove the article.

Blow moulding is used for making plastic bottles, toys, doll bodies and many other items.

(a)3. Extrusion Moulding: Polymer sheets and films can be produced using a flat extrusion die. These are advantages of extrusion process. The tooling cost is low compared to injection moulding. Material thickness can be controlled. In addition production rates are high and intricate profiles can be produced.



(a)4. Thermoforming: It consists of heating a thermoplastic sheet until it softens and then forcing it to confirm to some mould either by vacuum or air pressure.

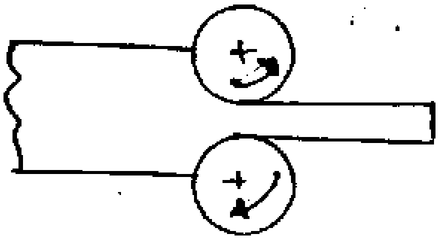


(a) Heating of thermoplastic sheet (b) Vacuum is applied to the mould

Thermoforming Process

The products made by thermoforming are jelly containers used in restaurants, refrigerator inner panels, packing containers etc…

(a)5. Calendering: This is an intermediate process in which extruded thermoplastic sections are reduced to sheets of films.



Calendering of Thermoplastic

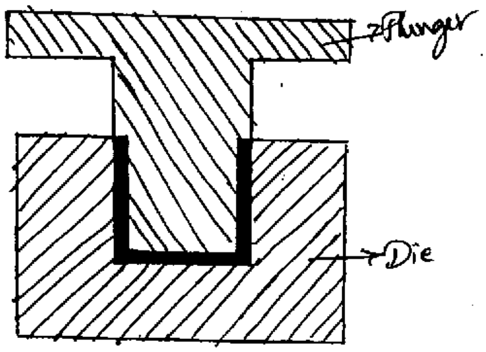
(b)1. Compression Molding: This is usually for thermosetting plastics. In compression moulding thermosetting material is placed in heated mould (female die).

The upper part of the mould is brought down to compress the material into the required shape and density. When the mould is closed, the material undergoes a chemical change or polymerization that hardens it.

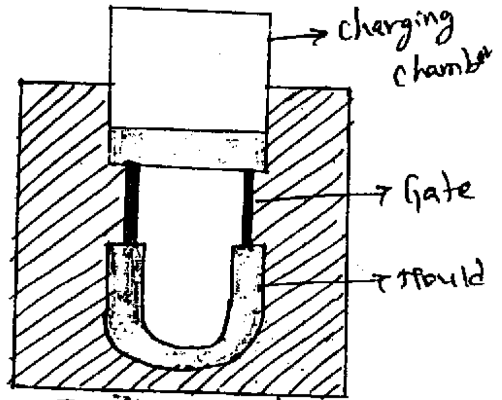
The moulding temperature ranges from 150 – 180°C. The moulding pressure ranges from 150 – 500 kg/cm2. The time required to harden the product ranges from 1 to 1.5 minutes. It also depends on the thickness of the product.

The products made by this process include dishes, container caps etc…

(b)2. Transfer Moulding: Transfer moulding is variation of compression moulding in which heat and pressure is applied to the moulding materials outside the mould until they become fluid. The fluid material is then forced through a series of channels from external chamber to the mould cavity where final cure takes place.



Compression Moulding



Transfer Moulding